ENGINEERING AND BACTERIOLOGICAL STUDIES RELATIVE TO MAINTAINING QUALITY OF SOFT-SHELL CLAMS (*Mya arenaria*)

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ABSTRACT

Quality maintenance of soft-shell clams, Mya arenaria, from harvest through processing was the focus of this project. The project was divided into several sections definable as: 1) depuration studies, 2) growth rate of bacteria in clams under constant temperature environment, 3) cooling methods for clams, 4) on-board harvesting boat cooling studies, and 5) engineering analysis of the industry.

Depuration studies resulted in development of a very adequate ultraviolet (UV) sterilization unit, an efficient aeration system and a unique particulate filter with built-in backwashing options. The total depuration system did not adequately depurate clams in the small number of tests run.

Clams were placed in a controlled temperature chamber and bacterial count monitored over about a 60 hour period. Temperatures of 40°, 50°, 60°, 70°, and where needed, 80° and 90°F were used while standard plate count, total coliform and fecal coliform count were monitored. Results indicate bacteria in clams held at 50°F or below do not show significant growth in the 60 hour storage period monitored. Clams harvested in four seasonal periods showed essentially no differences in bacterial growth due to seasonal effects.

Cooling methods for soft-shell clams were investigated using three cooling mediums (ice, dry ice and mechanical refrigeration), four container designs and three cooling systems. Three of the four container designs were tapered as a standard clam (or apple) basket but had varying amounts of open space in the sides. The fourth container was a rectangular solid and sized to tightly fit into the cooling chamber. Cooling systems consisted of a static box (natural convection only), a one-bushel forced air unit and a six-bushel forced air unit.

The natural convection system proved unsatisfactory with all containers tested and all three cooling mediums, primarily due to very slow cooling rate. Cooling rate was slowest with ice, intermediate with dry ice and fastest using mechanical refrigeration in the one-bushel forced air unit. However, freezing and CO_2 exposure could cause damage to the clams using dry ice and extended holding periods. Ice

proved a satisfactory cooling medium in the six-bushel unit under simulated commercial loading conditions.

The solid rectangular container cooled fastest due to better air flow through the container. The three tapered containers cooled at a rate in direct proportion to the amount of open area in the sides of the basket. Greater open area resulted in faster cooling if all other parameters remained constant.

On-board harvesting boat cooling studies were designed to determine if immediate on-board cooling was better than conventional industry practice. It appears that cooling quickly upon harvest compared to placing the clams under refrigeration six hours after harvest (approximating conventional industry practice) had the following result 49 hours after harvest: plate counts were not significantly different; total coliform counts were significantly lower in clams cooled on-board; fecal coliform counts were not significantly different.

An engineering analysis was completed for the Maryland soft-shell clam industry. This analysis resulted in an operations-process chart detailing all processes a clam undergoes from harvest to market. Recommendations were made to improve processing and transporting practices in the industry. In addition, relationships were developed to predict the meat weight and weight of other clam parts from shell length or live weight measurements. Other information developed included: 1) clam shucking rates for hand shuckers, 2) cooling rates in industry coolers, 3) effect of shading full baskets of clams while on board harvesting boats.

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I. INTRODUCTION

The Maryland soft shell clam industry has been troubled by high bacterial counts, particularly during warmer summer months. Several phenomena have been suggested as possible causes among which are: 1) environmental stresses of low salinity, high temperatures or heavy harvesting pressure; 2) poor handling of the clams after harvest; 3) accidental contamination of the clams with bacteria sometime between harvest and market; 4) poor sanitation practices during handling, transportation, and processing; 5) pollution of clam growing areas by natural or man-made materials, etc. Although many theories have been put forth, none have been proven to be the primary cause.

Because the soft shell clam industry is a major contributor to the total Maryland seafood industry (Table 1) and economy of the State, the industry, management agencies, and regulatory agencies were concerned over the bacterial problem. As a result of this concern, the research described in this report was initiated in the Spring of 1972. Funding of the research was a cooperative effort of the Office of Sea Grant in the National Oceanic and Atmospheric Administration, the Maryland Department of Natural Resources and the Maryland Department of Health and Mental Hygiene. Cooperation of the Chesapeake Bay Seafood Industries Association and several Maryland watermen and soft shell clam processors made it possible to carry out project objectives. The actual project work was carried out by personnel from the Agricultural Engineering, Veterinary Science and Dairy Science Departments of the University of Maryland.

Initial project focus was to develop an engineering and product quality survey of the soft shell clam industry in order to define the extent and source of the high bacterial counts. Unfortunately, hurricane Agnes struck the Chesapeake Bay and its drainage basin on June 1923, 1972 before significant progress was made with the survey. This storm dumped massive amounts of water (over 12 inches of rain in 24 hours in many areas) over a large portion of the total drainage basin. The massive fresh water influx into the Bay reduced salinity far below normal throughout the Bay. Extremely high air temperatures

for an extended period immediately after Agnes rapidly increased water temperatures. The combined stress of warm water and extremely low salinity caused mass mortality of soft shell clams. Flooding of sewage treatment plants and other facilities located along rivers flowing into the Chesapeake Bay, due to the extremely high runoff rates during and immediately after the storm, contaminated water entering the Bay. Thus, immediately after hurricane Agnes and for the remainder of 1972 harvesting of soft shell clams was prohibited in the entire Bay for health reasons.

TABLE 1. POUNDS OF SOFT-SHELL CLAM MEATS HARVESTED IN MARYLAND AND THEIR DOCK SIDE VALUE, 1960-1975

Year	Pounds Harvested	Value in Dollars	Reference
1960	5,568,800	1,593,802	a
1961	4,692,000	1,231,082	a
1962	6,767,400	1,513,249	a
1963	6,858,500	1,499,405	a
1964	8,164,300	1,667,098	a
1965	7,654,400	1,548,310	a
1966	7,006,900	1,649,563	a
1967	5,212,300	1,610,589	a
1968	5,578,900	1,869,705	a
1969	7,909,500	2,800,344	a
1970	6,221,300	2,433,724	a
1971	5,986,128	2,993,064	b
1972	1,949,500	1,014,782	c
1973	668,688	557,240	d
1974	1,766,136	1,501,210	e
1975	1,057,176	1,014,842	f

[a]Marsco and Tinklepaugh, 1974

[b]Maryland Landings, 1971

[c]Fishery Statistics of United States, 1972

[d]Maryland Landings, 1973

[e]Maryland Landings, December 1974

[f]Maryland Landings, December 1975

Clam mortalities were so severe the clam bottom was kept closed for conservation purposes until June 1, 1973. On June 1 limited clam bottom was opened for harvest with strict harvest limits imposed for resource conservation. However, on June 23, 1973 harvest was again stopped because clam bacterial levels at the processing plants were far too high for safety. The season remained closed until August 27, 1973.

Since the clam season was closed except for a three week period between June 20, 1972 and August 27, 1973, the commercial harvest of clams was prohibited. Clam processing operations were also closed due to lack of clams. This made it impossible to conduct an engineering and product quality survey of the industry. Thus, project priorities were reordered and the work was conducted differently. However, the primary emphasis of the project was to look at various segments of the industry and to determine if alternative practices would reduce bacterial levels in the clams.

High bacterial levels appeared to be a particular problem in the warmer summer months. The closing of harvesting during hot weather would be one solution to the problem. Unfortunately, the primary marketing period for soft shell clams is summer, Table 2, and closing the industry during this period would destroy it. Thus, an attempt was made to develop solutions which would permit the industry to produce high quality clams year around.

TABLE 2. MARYLAND PRODUCTION AND DOCK SIDE VALUE OF SOFT-SHELL CLAMS HARVESTED BY MONTH FOR 1975

Month	Landings, lbs meat	Value, $	Reference[a]
Jan.	87,444	72,870	6679
Feb.	69,120	57,600	6698
March	86,544	72,120	6744
April	119,460	99,550	6763
May	121,620	101,350	6782
June	94,812	79,010	6803
July	143,628	128,667	6830
Aug.	90,984	136,476	6849
Sept.	27,780	41,670	6869
Oct.	10,620	16,815	6888
Nov.	12,144	20,240	6933
Dec.	7,992	13,320	6952

[a]Numbers listed under reference are the current Fisheries Statistics number as listed in the References section of this report.

II. CLOSED CYCLE DEPURATION SYSTEM AND HOLDING TANK

Purpose

Two of the original objectives of this investigation were concerned with the closed cycle depuration of clams and the effect of air temperature on the bacteria growth rate of clams in storage. As the latter tests were to utilize clams harvested from different locations as well as over a period of time spanning several seasons, it was anticipated that these variations would influence the initial bacterial level in the clams at harvest.

Therefore, prior to the start of the bacteria growth rate (storage) tests, a one-bushel size depuration system was constructed. Clams obtained for the storage tests were first placed in the depuration system for a period of 24-48 hours prior to their transfer to storage in an attempt to establish a relatively constant bacterial count for all clams as placed in storage regardless of initial bacterial load at harvest.

Equipment Description - One-Bushel Depuration System

The depuration unit was of closed system design and used municipal tap water and Instant Ocean,[a] an artificial sea salt. Sufficient salt was added to achieve a salinity of 8-10 ppt as determined by a Yellow Springs Instruments Model 33 Salinity Meter.

The major components of the system included a water holding tank, aerator, water sterilizer, clam holding tank with rack, sand filter, water chiller, a lifting hoist and miscellaneous pumps and plumbing.

The main water holding tank also served as the base for the rest of the system. Tank size was 4 X 8 by 2 feet deep constructed of

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[a]Trade name of an artificial sea salt manufactured by Aquariums System, Inc. Trade names are used for clarity and their use does not imply endorsement of the product by the University of Maryland or any funding agency.

5/8 inch plywood glued together with inside corner fillets and outside 2 X 3 inch wood bracing. Located in one corner was a 12 inch square sump to allow complete pump-out of the entire contents with a submersible pump. The inside surface of the tank was coated with Shell Co. Epon 828 epoxy resin using hardening agent T.

Water was pumped from the sump of the main tank to the top of the aerator, Fig. 1. The upper four 11 X 18 by 1 inch deep trays were perforated with 1/8 inch diameter holes spaced 1 inch on center. The 4 inch deep bottom tray had a stand pipe overflow to the main tank which maintained a constant water level for that portion of the aerated water going to the ultraviolet (UV) treatment unit. Aeration was more than sufficient to maintain the water near saturation. Water dropping between trays splashed excessively, necessitating the installation of a splash shield around the aerator.

Water at the rate of one GPM was carried by gravity from the aerator to the water treatment unit, Fig. 2. This unit was constructed of epoxy coated wood. Water was directed over and between baffles so that it followed a 90 inch long path under three G30T8 30 watt ultraviolet lamps with reflectors. The majority of the UV lamp output was concentrated near a wavelength of 2537 Å. Maximum water depth was 1 inch and the center of each lamp was located 5 inches above the water surface. Slow deterioration of the epoxy coating was experienced due to the high UV energy levels and/or the moderate effectiveness with which the epoxy adhered to wood.

The germicidal effectiveness of the UV unit is indicated in Table 3 both at 1 GPM and at selected higher rates.

Plate count reduction at the 1 GPM flow rate was satisfactory except for treated tests 21 and 46. Total coliform reduction was good. At higher flow rates plate count reduction was less effective. The germicidal lamps were in use for 2/3 of their rated life as of test #50.

Treated water flowed by gravity from the UV treatment unit to one end of the clam holding tank. The tank consisted of a cast iron bathtub coated on the inside with epoxy resin. An adjustable overflow at the downstream end provided water level control. An emergency

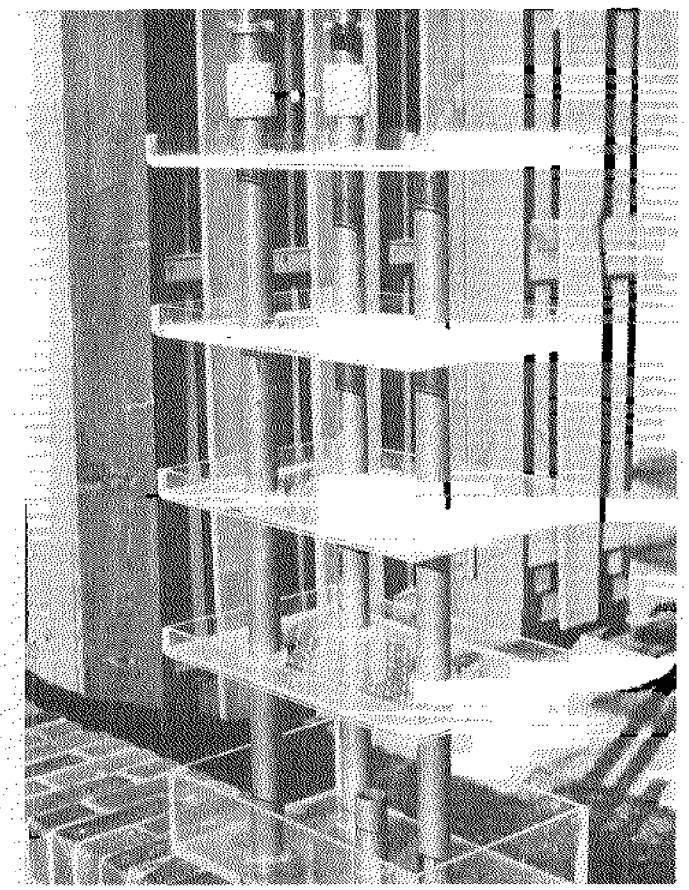

FIG. 1 Aerator unit for the one-bushel depuration system.

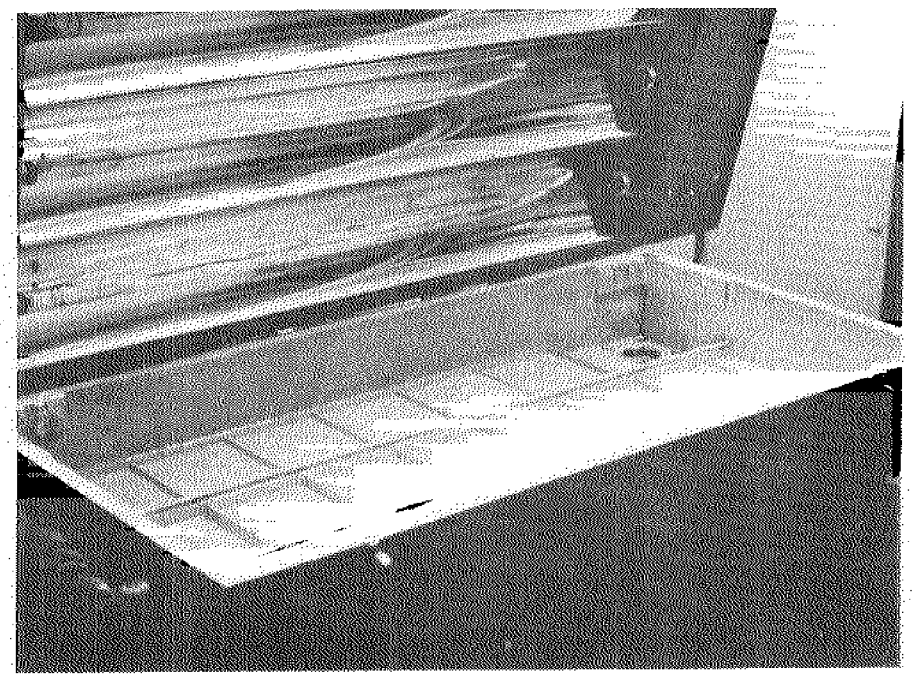

FIG. 2 Inside of UV water treatment unit.

TABLE 3. GERMICIDAL EFFECTIVENESS OF UV WATER TREATING UNIT.

Sample numbers	Flow rate, gpm	Plate Count/g		Total Coliform/per g		Fecal Coliform/per g	
		untreated	treated	untreated	treated	untreated	treated
1,2	1.0	TNTC*	5	1,000	<1.8	<1.8	<1.8
3,4	1.0	TNTC	16	≥2,400	<1.8	<1.8	<1.8
6,5	1.0	TNTC	20	920	<1.8	<1.8	<1.8
9,8	1.0	TNTC	<1	240	<1.8	<2	<1.8
11,12	1.0	TNTC	<1	240	<1.8	<2	<1.8
23,21	1.0	542	35	110	<1.8	<2	<1.8
24,25	1.0	716	7	2,200	<1.8	<1.8	<1.8
38,39	1.0	9330	<1	27	<1.8	---	<1.8
43,44	1.0	TNTC	26	23	<1.8	<1.8	<1.8
45,46	1.0	1008	34	11	<1.8	<1.8	<1.8
50,51	1.23	952	56	17	<1.8	<1.8	<1.8
50,52	1.51	952	64	17	<1.8	<1.8	<1.8
50,53	1.95	952	100	17	<1.8	<1.8	<1.8
54,56	1.49	1000	78	<1.8	<1.8	<1.8	<1.8
54,57	1.49	1000	96	<1.8	<1.8	<1.8	<1.8
54,55	1.93	1000	226	<1.8	2	<1.8	<1.8

*TNTC = too numerous to count

spillway discharged water directly to the main holding tank in the event the main overflow clogged. The original tub drain was plumbed with 1 1/4 inch pipe to both the sand filter and a waste sump.

The original trays for holding clams were made of wood. They proved to be unsuitable as they floated and the slotted design allowed siphons to get wedged between the slats. Wood is also not a good material from a sanitary standpoint.

A set of four trays were constructed of Plexiglas and polyethylene mesh, Figs. 3 and 4. They were tied together with nylon rope in such a fashion that when all trays were suspended on the ropes, there was an 8 inch access space between trays. When in water, the trays rested on top of each other. A winch and cable assembly, Fig. 5, facilitated lifting the trays out of the tank.

Normal overflow from the clam tank gravity fed into a 11 X 11 inch sand filter (Fig. 6). Experimentation with particle sizes for the upper layer of sand determined that particles smaller than 20 mesh (0.0331 inch openings) would clog rapidly. Water to be treated flowed downward through the sand layers, through a perforated false bottom, through the side of the filter then up an adjustable stand pipe. In this manner the water level was maintained above the sand level to prevent erosion of the top layer of sand by the incoming water. The outflow pipe was also connected to a tap water supply for reverse flushing. A series of baffles below the bottom gravel layer reduced the high velocity inlet water during back flushing to a gentle upward flow that was uniform across the entire bottom of the filter. Two 1 1/4 inch pipes carried the back flush water to a waste sump. Capacity of these two pipes limited the flushing rate to a maximum of 18.3 GPM per ft^2. This rate was sufficient for washing and is in the middle of the recommended range for this type of filter. Mechanical agitation of the upper sand layer improved the back flushing process.

Since the ambient room temperature of $75^{\circ}F$ or above was too high for the clams, cooling of the water in the system was required. A water-alcohol solution cooled by an Edwards Engineering Company CC-1A packaged water chiller, Fig. 7, circulated through a heat exchanger constructed of 50 feet of 1 inch polyethylene pipe placed in a horizontal spiral coil in the bottom of the main holding tank. The low

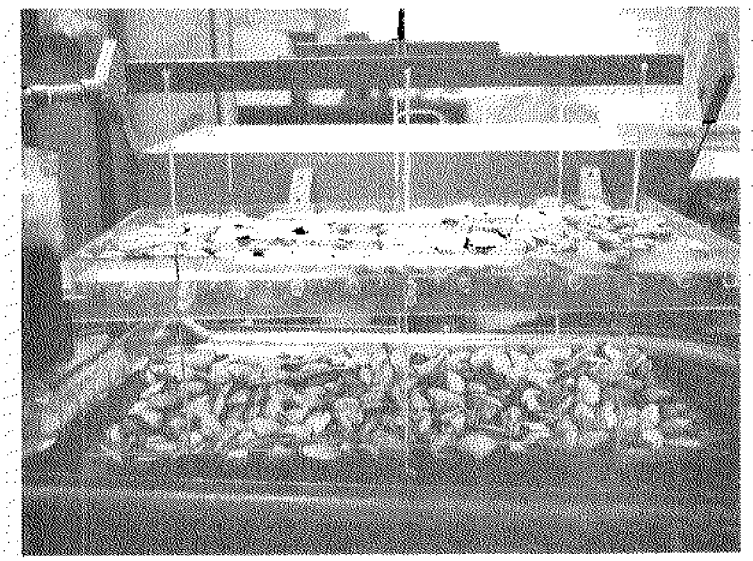

FIG. 3 Upper two Plexiglas clam trays positioned for servicing.

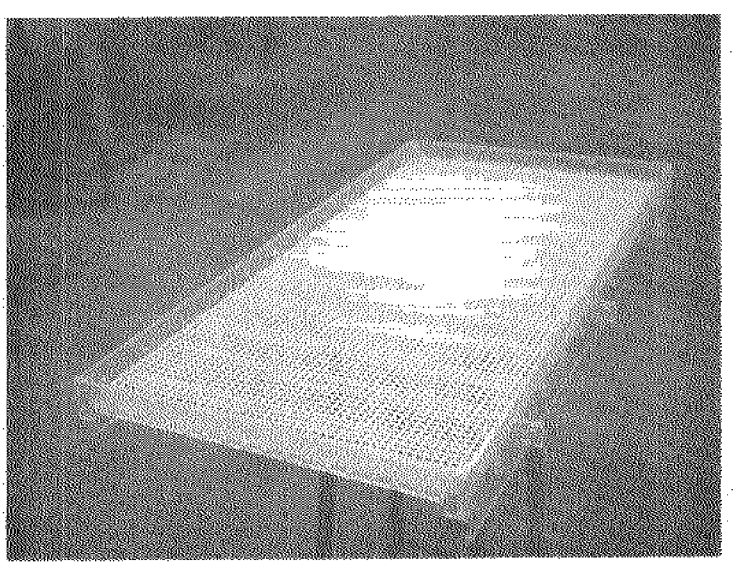

Fig. 4 Detail of clam tray.

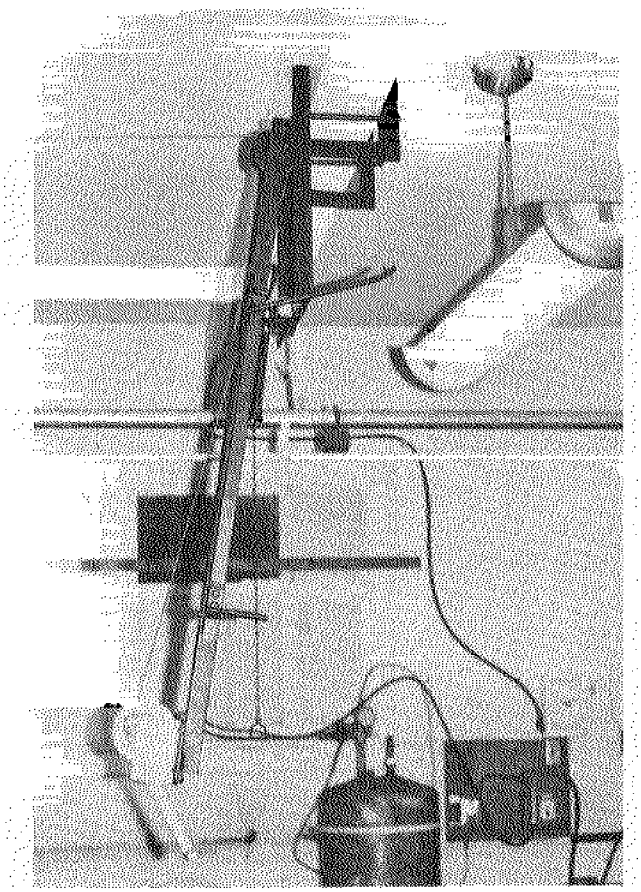

FIG. 5 Clam tray winch and hoist assembly

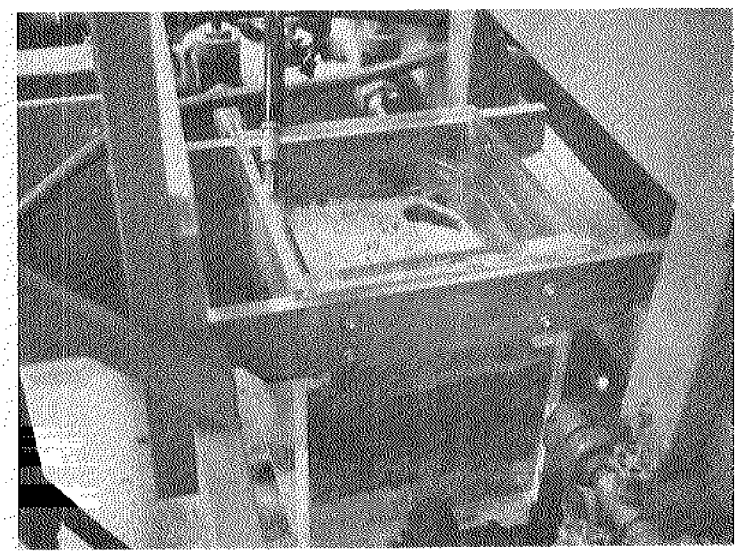

FIG. 6 Main sand filter for holding system.

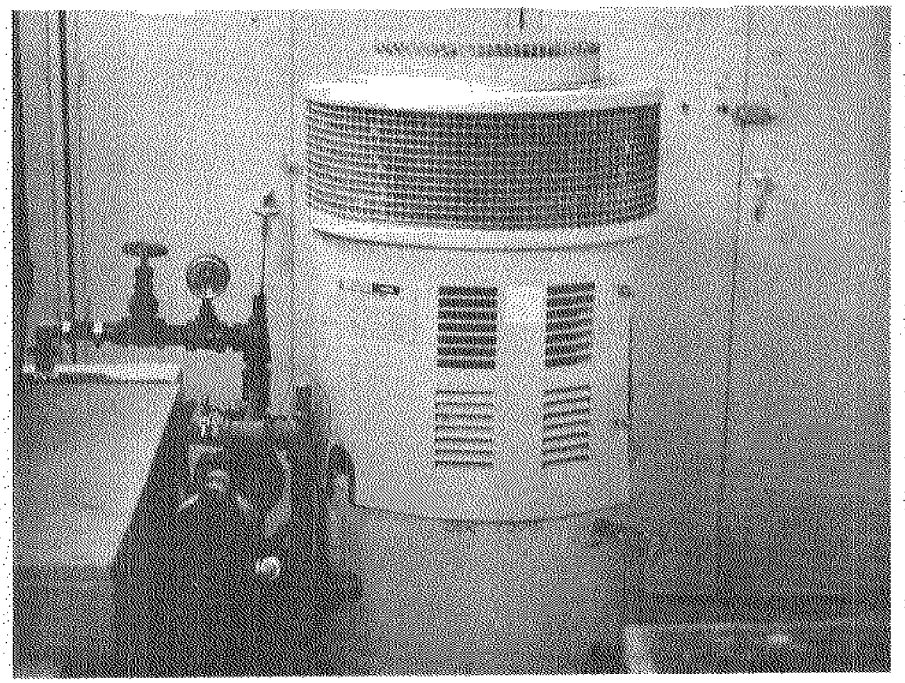

FIG. 7 One-ton water chiller for depuration system.

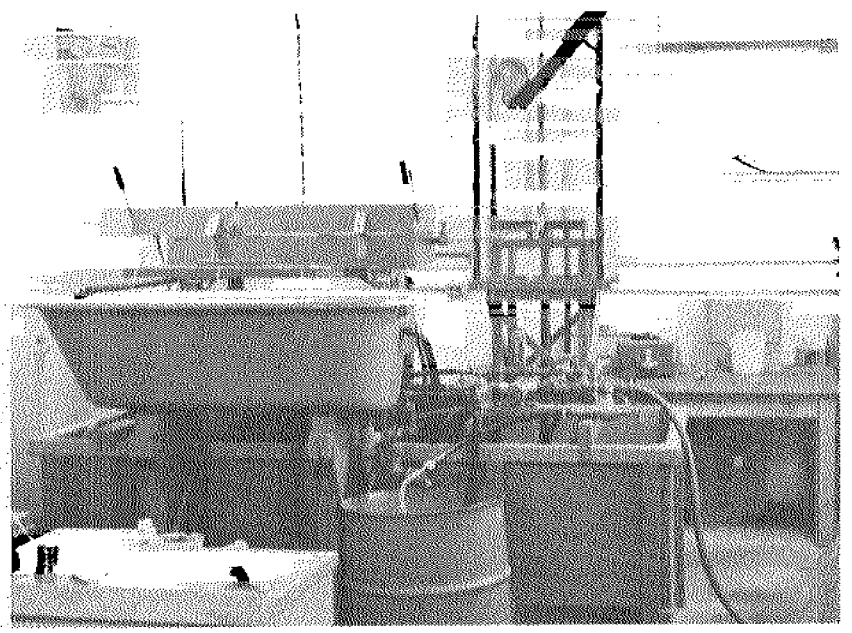

FIG. 8 One bushel depuration system.

thermal conductivity of the polyethylene was accepted as a trade-off to get its resistance to salt water corrosion. The system was adequate to maintain 61^{o}-65^{o}F in the clam tank.

The submersible pump, a Little Giant model 3E-12N, provided circulation through the depuration system. All plumbing was either black polyethylene semi-flexible pipe, schedule 80 PVC pipe or Tygon tubing. Fig. 8 shows the assembled system.

Experience with the one-bushel system demonstrated that it was too large to be fully tested and optimized. Construction was initiated on a depuration unit having four separate 1/4 bushel systems. Thus with a one bushel lot of clams, any test variable could be evaluated at four different levels of that variable at once (eg. water temperature, salinity, salt type, flow rate, chemical composition, oxygen level, and tank configuration). Construction was initiated and a support basin, sump pump and 3 ton water chiller were installed, Fig. 9. At this point other objectives of the project were deemed more important and no further investigations of depuration were conducted. However both systems were used extensively as holding tanks for up to a combined total of eight bushels of clams for use in the cooling studies.

A 7 inch diameter sand filter was designed for use with the four 1/4 bushel depuration systems. It was designed to be removable from its point of use to a washing station for back flushing. Fig. 10 shows the filter, washing base and collector. Fig. 11 shows the filter in use while Fig. 12 shows the filter with the flushing base and collector during the back flushing process. Holes in the filter bottom and in the flushing base were aligned when the filter was placed on the base. An O-ring provided sealing between the filter and the base. The collector, held on top of the filter by hand, collected the waste water and directed it to a drain. The base was connected through a flow control valve to a water supply. Water flowed into the base, up through the aligned holes and up through the sand. Mechanical agitation of the sand aided the reverse flushing process. Although the system worked reasonably well, the addition of a clamping device to hold the base, filter, and collector tightly together would improve operation. This type of filter installation eliminated the need for extensive permanent backwash plumbing at each filter.

FIG. 9 Support basin and water chiller for the 4-unit depuration system, set up as a holding tank.

FIG. 10 Seven inch sand filter, washing base and collector.

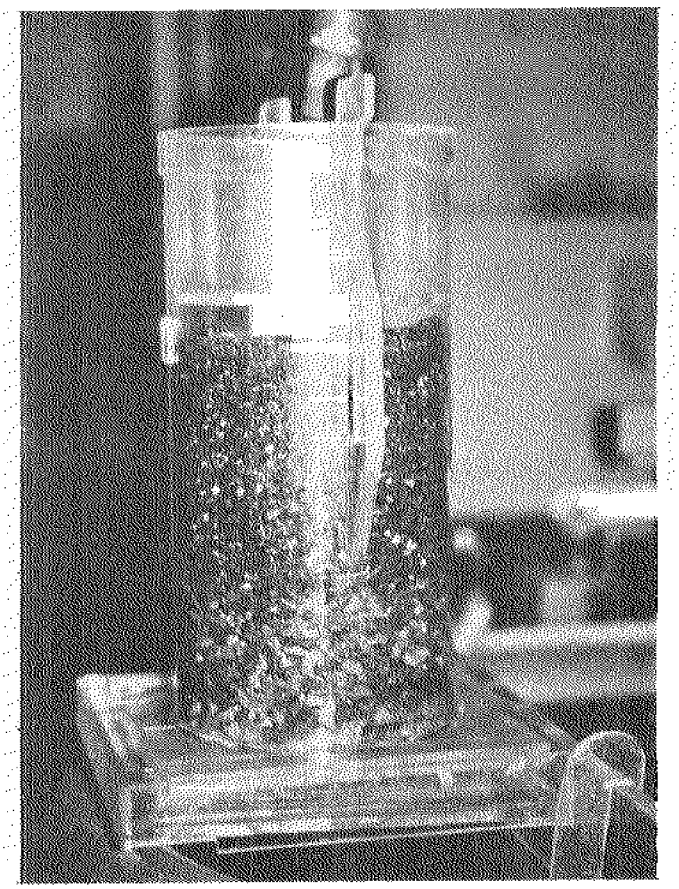

FIG. 11 Sand filter in use in holding system.

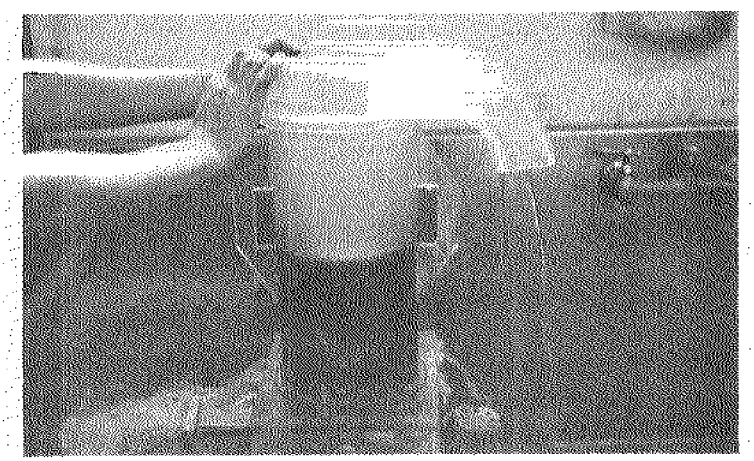

FIG. 12 Method for back washing of seven inch sand filter.

Operation - One-Bushel System

The conditions within the depuration system were stabilized prior to introduction of clams. Water and salt were added and circulation started in order to add oxygen and remove chlorine. Only healthy, unbroken clams were placed on the trays. After placement the clams were rinsed with tap water, this water going to waste. The racks were lowered into the clam tank and the water supply from the aerator started. Filling time to cover the top layer was about 20 minutes. Every 24 hours during operation the inlet water to the clam tank was cut off and the clam tank was drained through the sand filter. The clams and tank were rinsed with tap water, this water also going to waste. While the clam tank was refilling from the UV treated water supply, the sand filter was reverse flushed. An intermediate collecting barrel (sump) was used to temporarily hold the flushing water as the 18 gpm flushing rate was greater than the volume that could be pumped to the nearest sanitary sewer connection. Make-up water (tap water) was added to the system as needed.

Results

The one-bushel depuration system was evaluated during the Spring of 1973. Fig. 13 provides a graphical presentation of results from plate count analysis while Fig. 14 provides similar results from total coliform analysis. Statistical analysis of data for each test showed that only test numbers 7 and 8 on the plate count data showed a slope different than zero. Even for these two curves the slopes were just significant at the 5 percent level. Thus, for practical purposes no significant depuration occurred for either plate count or total coliform. The reason for this is unknown, although it is probably due to incorrect or rapid changes in temperature and/or salinity between the depuration water and harvest area water.

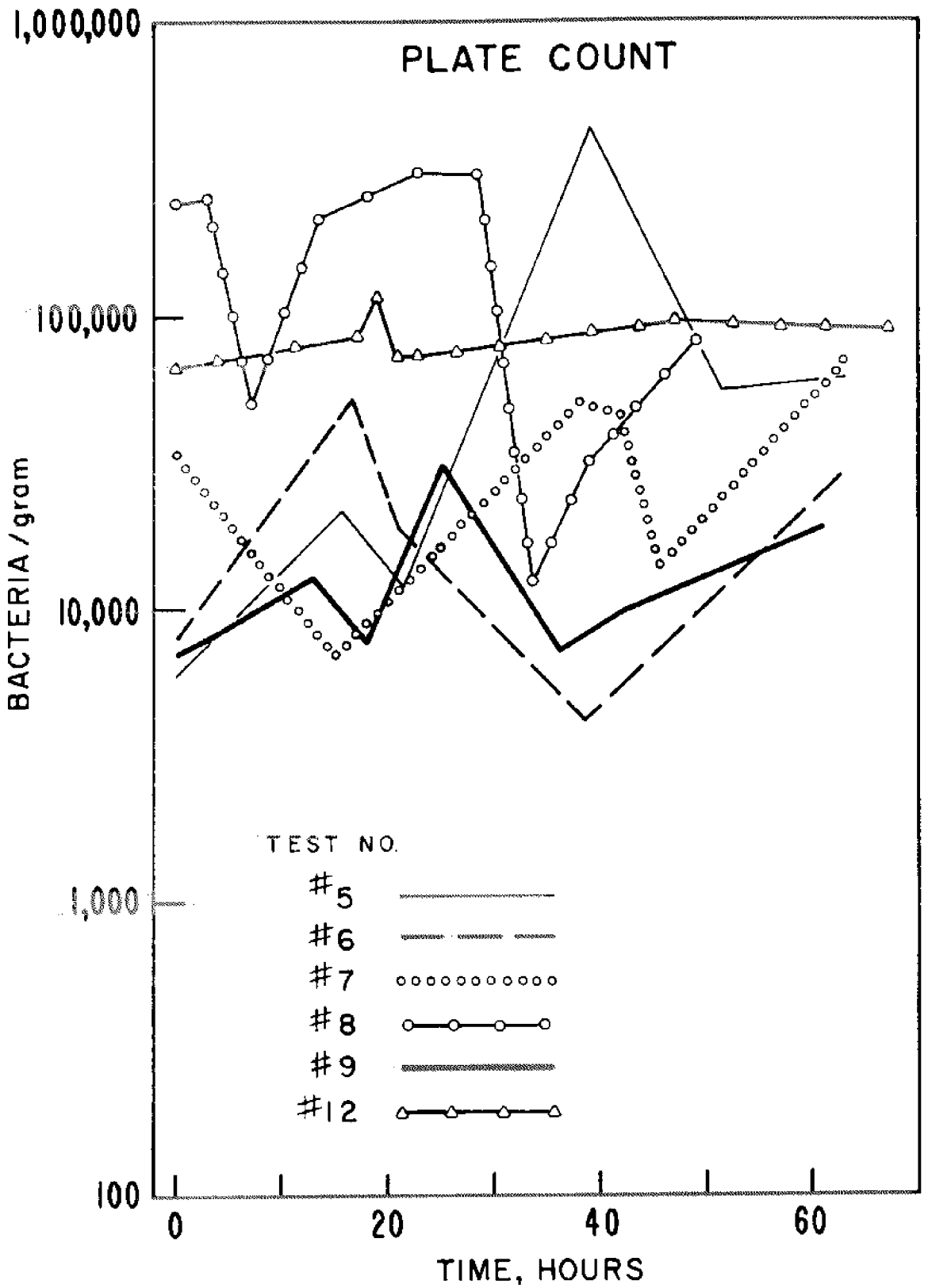

FIG. 13 Plate count results, one-bushel depuration system.

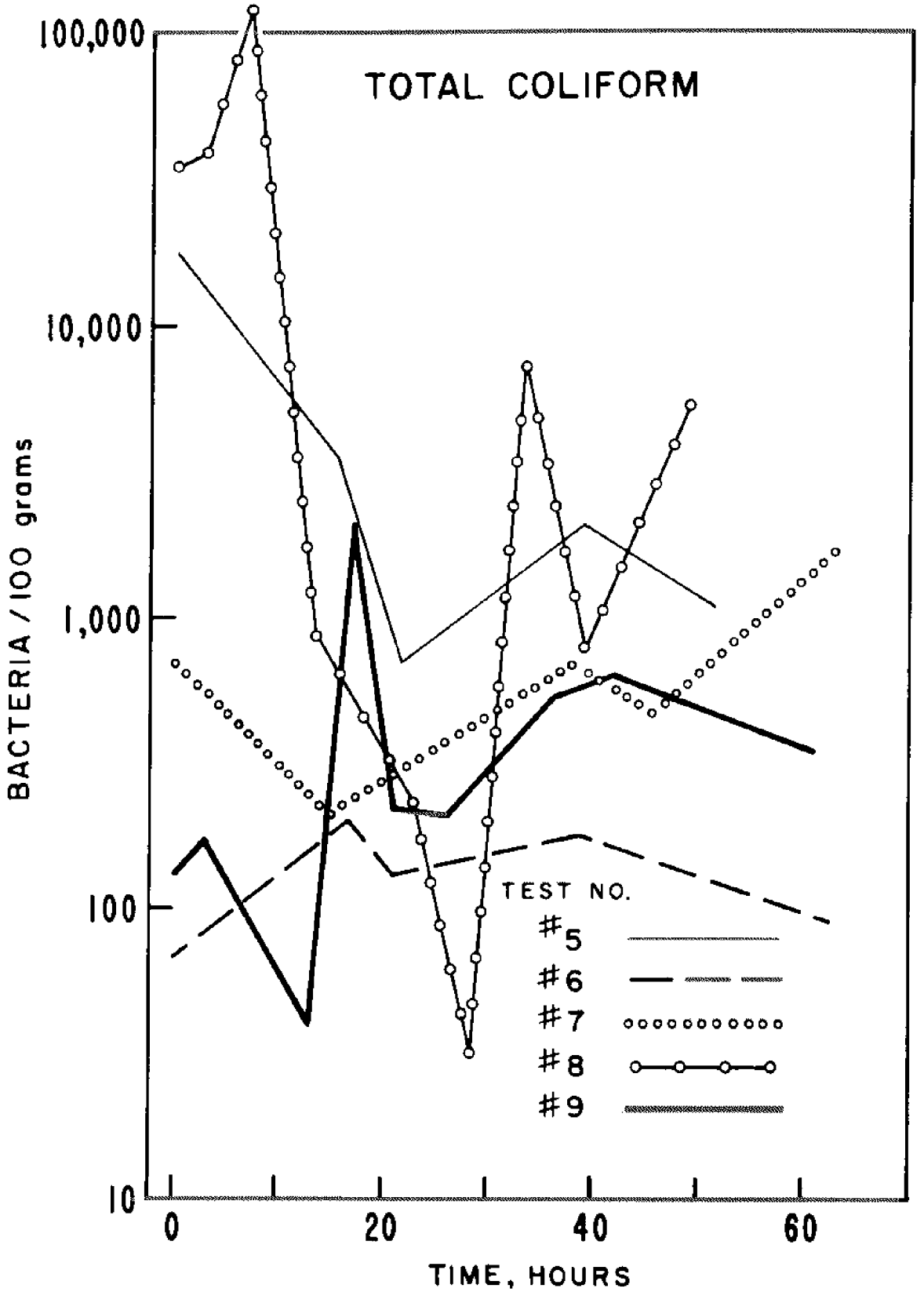

FIG. 14 Total coliform results, one-bushel depuration system.

Conclusions

The following conclusions can be drawn from the depuration research:

1. The UV unit provided good disinfection of the inflow water.

2. The aerator provided water approaching oxygen saturation.

3. An easily backwashed portable sand filter was designed.

4. The total depuration system was ineffective as operated for an unknown reason.

III. GROWTH RATE OF BACTERIA IN SHELLSTOCK DURING STORAGE AT SELECTED TEMPERATURES

Objectives

The effectiveness of refrigeration in stabilizing the bacteria levels in meat and fish is well established. The soft shell clam is somewhat unique in that the clam is kept alive after harvest until it is shucked or steamed. A procedure for treating shellstock between harvest and processing should be designed to: 1. keep the clam alive, 2. stabilize the level of bacteria within the clam, and 3. prevent any changes to the meat such as taste, texture or appearance.

Current industry practice is to store clam shellstock at ambient air temperature during the harvest and transport phases, then to place the baskets in refrigerated walk-in coolers. The objective of the study herein discussed is to determine the effectiveness of various holding temperatures in controlling bacterial growth in live soft-shell clams. Temperature levels selected were $40^{\circ}F$ through $70^{\circ}F$ in 10 degree increments with several additional tests at $80^{\circ}F$ and $90^{\circ}F$.

Equipment

A constant storage environment was maintained by placing the clams in a controlled environmental chamber. The chamber interior temperature could be held within $\pm 2^{\circ}F$ at any temperature between 34° and $100^{\circ}F$. The chamber functioned by alternately operating heating and cooling systems. Since condensation on the cooling coils was piped out of the chamber during the heating cycle, a DeVilbiss Model 280 portable mist type humidifier was used to maintain a high humidity within the chamber and prevent drying of the clams. A Bendix Model 566 portable psychrometer was used to measure humidity within the chamber during tests.

Clams were held within the chamber on 1/2 inch mesh racks approximately 36 inches long by 18 inches wide, Fig. 15. These racks were elevated six inches above drip pans. The pans collected any fluids

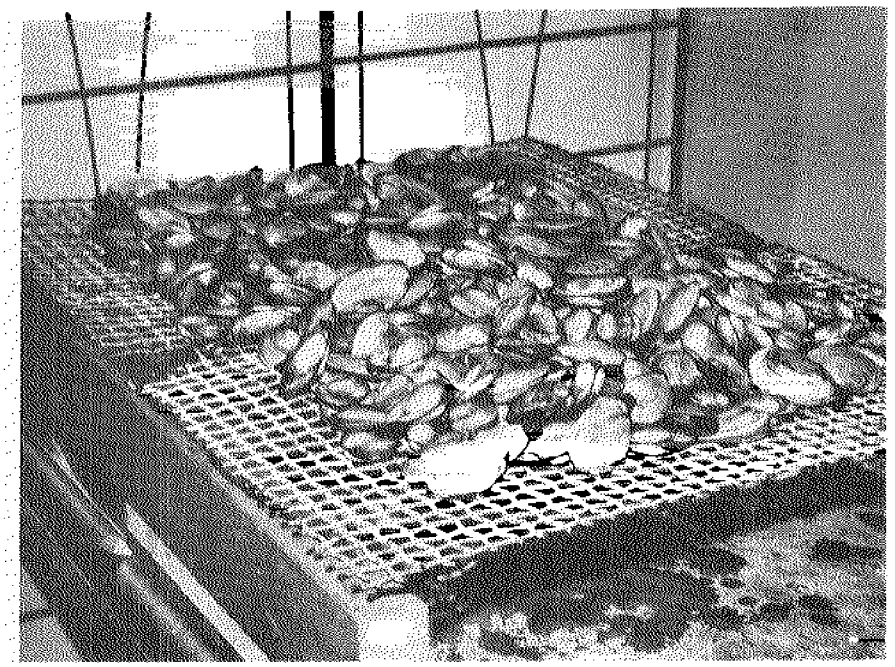

FIG. 15 Method of supporting clams during the bacterial growth rate (storage) tests.

dripping from the clams which kept the chamber clean. The six inch spacing between rack and pan prevented clam siphons from becoming accidently contaminated if the siphon hung below the wire mesh.

Procedure

Clam specimens used in the chamber tests were either purchased from commercial watermen or provided by the Maryland Department of Natural Resources. The clams were harvested in the morning and reached the dock by early afternoon where they were picked up by project personnel. Project personnel had no control over harvest time, harvest location or handling prior to pickup other than verbal assurance of recent harvest. Since the clams were harvested directly into one-bushel baskets, they were purchased in these same containers, usually one bushel at each pickup. The clams were transported to the laboratory in the trunk of a car or occasionally in the back of a pickup truck. If transported by truck, they were covered to prevent air drying during transport.

Clams in the Spring 1973 series of tests, the first set run, were placed in the one-bushel depuration system for 24 to 48 hours prior to being placed in the environmentally controlled test chambers. The depuration system was used in an attempt to reduce variability in initial clam bacterial counts harvested from different locations. However, bacterial analysis of clams from the depuration system revealed only a small reduction in bacteria levels with time. Thus, in all chamber tests after the Spring 1973 series, the clams were placed directly in the environmental test chamber from the transport vehicle, eliminating the depuration step.

Chamber temperature was preset and the desired temperature established prior to introduction of the clams. The screens for holding clams were autoclaved and placed in the chamber immediately before the clams were hand placed into the screens. Clams that were noticeably sick, injured or had broken shells were discarded. There was no discrimination by size as most clams were close to the 2 1/4 inch minimum legal length. For the majority of tests conducted in winter, incoming clam temperature was within $10^{\circ}F$ of the chamber temperature.

Thus, relative to the total test duration, a negligible time period was needed for the clams to reach chamber temperature. Summer tests at 40°F and 50°F were always started with the clams warmer than the chamber setting.

Clams were sampled periodically throughout the test for bacterial analysis, one sample consisting of enough clams to fill a 6 x 8 inch polyethylene bag or approximately 12 clams. Time of sampling was determined by the working hours of the laboratory technician and normal operating hours of the Animal Health Laboratory. An experienced technician could analyze six samples received by 9 AM plus six samples received by 2 PM for two days running plus six samples the morning of the third day for a total of thirty samples per week. Some of the storage tests generated fewer than 30 samples due to concurrent sampling from the depuration system. Samples taken at times other than 9 AM or 3 PM (i.e., 12 noon, 6 PM or 11 PM) were refrigerated at approximately 34°F until the next normal submission time.

The sampled clams were analyzed for standard plate count, total coliform numbers and fecal coliform count using standard methods (procedures summarized in Appendix C). Plate counts were determined using direct colony counts while total and fecal coliform counts were carried out using the most probable number and a five tube dilution. Gas production indicated presence of coliforms.

Results

Results of the chamber tests are presented on semilogarithmic plots in Appendix A. The graphical results are shown by test series. The Spring 1973 test series (done from 4-13-73 to 6-15-73) is shown in Appendix A-1; the Winter 1973-74 series (done from 9-4-73 to 3-28-74) is shown in Appendix A-2; the Summer 1974 series (done from 4-22-74 to 11-6-74) is shown in Appendix A-3 and the Winter 1974-75 series (done from 2-4-75 to 4-11-75) is shown in Appendix A-4. Table 4 summarizes the number of tests run at each temperature within each series.

Within each series the individual tests are arranged as follows in Appendix A. All plate count results are shown first, starting with the 40°F tests and progressing to higher temperatures. Plate count data

TABLE 4. SUMMARY OF CLAM STORAGE CHAMBER TEST DATA

Test Series	Chamber temp., °F	Test no.	No. of tests	No. of Data Points: Plate count	Total coliform	Fecal coliform
Spring 1973	40	15, 17	2	10	10	-
	50	16, 18, 33, 34 37, 38	6	38	14	-
	60	29, 30, 35, 36	4	20	20	-
	70	25, 26, 31, 32	4	20	20	-
	80	23, 24	2	10	10	-
	90	21, 22	2	10	10	-
Winter 1973-74	40	45, 46, 47, 57	4	25	25	14
	50	41, 50, 51, 53	4	33	33	33
	60	39, 52, 55, 56	4	32	32	22
	70	40, 49, 54	3	18	19	19
	80	42, 58	2	13	13	13
	90	44	1	4	4	4
Summer 1974	40	63, 65, 66, 68, 69	5	34	34	34
	50	61, 62, 64	3	28	30	20
	60	60, 67, 1R, 2R	4	24	24	24
	70	59	1	9	9	9
Winter 1974-75	40	4R, 8R	2	10	10	5
	50	5R, 9R	2	10	10	10
	60	6R, 10R	2	10	10	10
	70	7R, 11R	2	12	10	5

points from all individual tests within the series done at the same temperature are shown on one graph. The single line on each graph is derived by treating all data points as if they were derived from one test and calculating a linear least squares regression line using the $\log_{10}$ of count versus time in hours. Each point on the graph is the average of from 1 to 6 samples. The average was calculated by averaging the individual logarithms from samples taken at the same time. This assumes a logarithmic growth curve for the bacteria. After the individual count graphs for each series is a summary graph. This graph has the calculated regression lines for each temperature within the series and allows visual comparison of the regression lines for all temperatures within the series. After the plate count summary graph, total coliform data is presented in a similar arrangement. Where sufficient data was available, fecal coliform results for the series are presented after the total coliform summary graph. A similar arrangement is followed for each test series.

The data were analyzed using linear regression applied to the logarithm (to the base 10) of the appropriate bacterial count and the time in hours after the clams were placed in the controlled environmental chamber. Slopes and elevations of these linear regression lines were calculated and compared using the Simultaneous Test Procedure (Sokal and Rohlf, 1969) to determine if slope and/or elevations of the curves were statistically different. A five percent level of significance was used. Two different analyses were run using this procedure. The first analysis considered all tests run at a particular temperature and determined if there were differences between tests run at different seasons. The second analysis grouped all data taken within a season and determined if there was a difference between bacterial growth rate in clams held at various temperatures.

Tables 5, 6 and 7 summarize the results of the first analysis where differences between seasons at each temperature are of interest. Table 5 shows the plate count results, Table 6 the total coliform results and Table 7 the fecal coliform results. The superscript letters beside the slope and elevation values indicate which values are significantly different than the others in the set. Values with the

same superscript are not significantly different from each other. Using the 40°F plate count data as an example, none of the slopes are significantly different from any of the others. In the elevations column (elevations are related to the zero time intercept), Sp73 is significantly different from W73-74 but not from S74 or W74-75. S74 is significantly different from W73-74 and W74-75 but not Sp73. W73-74 is significantly different from all the other values. Similar comparisons can be developed from the set of slopes and elevations for each temperature in Tables 5, 6 and 7. It should be noted that elevations are measures of differences in initial counts only when slopes are the same.

The slopes are a measure of the growth rate of bacteria within the environmental chamber. The elevations are generally a measure of the absolute bacterial count in the clams and are, thus, primarily a function of the initial bacterial count in the clams when they were placed in the chamber. Thus, slope differences are primarily due to experimental variables of season (in Tables 5, 6 and 7) and/or temperature, while elevation differences are due to uncontrollable variables.

In Tables 5, 6 and 7 slopes are significantly different only in the 60°F tests for plate counts and in the 70°F tests for total coliform. There are no known unusual circumstances which could explain these two cases. Thus, the test results must be considered correct. However, excluding these two cases there are no significant differences in slope (i.e., bacterial growth rate) due to harvesting season for plate counts, total coliform or fecal coliforms in the tests. Thus, one can generally say, based on the data available from these tests, that bacterial growth rate for the total bacterial population (plate count, total coliforms and fecal coliforms) is not dependent on the time of year in which the clams are harvested.

The effect of season on the regression curve elevations is variable. The reasons for this are not readily apparent. However, the wide variation in bacterial levels from one location to another is probably the major reason. The inherent variations found in all bacterial analysis add to these differences.

TABLE 5. REGRESSION SLOPES, ELEVATIONS AND CORRELATION COEFFICIENTS FOR PLATE COUNTS BY SEASON FOR VARIOUS TEMPERATURES. THE ELEVATIONS ARE GIVEN AS LOGARITHM TO THE BASE 10 OF THE BACTERIAL COUNT AND THE SLOPES ARE THE RATIO OF THE LOGARITHM OF BACTERIAL COUNT DIVIDED BY THE TIME IN HOURS SINCE THE TEST STARTED.

Temperature, °F	Season and Year*	Slope**	Elevations**	r
40	Sp73	0.0018^{a}	4.329^{ab}	0.09
	W73-74	0.0002^{a}	3.656^{c}	0.01
	S74	0.0045^{a}	4.294^{b}	0.22
	W74-75	-0.0042^{a}	4.807^{a}	-0.17
50	Sp73	0.0016^{a}	4.776^{a}	0.08
	W73-74	0.0021^{a}	3.813^{b}	0.16
	S74	0.0048^{a}	4.951^{a}	0.10
	W74-75	-0.0090^{a}	4.808^{a}	-0.43
60	Sp73	0.0153^{a}	4.791^{a}	0.62
	W73-74	-0.0022^{b}	3.787^{b}	-0.11
	S74	0.0126^{a}	4.711^{a}	0.40
	W74-75	0.0110^{a}	4.752^{a}	0.58
70	Sp73	0.0026^{a}	4.808^{a}	0.15
	W73-74	0.0183^{a}	4.188^{b}	0.48
	S74	0.0114^{a}	5.251^{a}	0.81
	W74-75	0.0035^{a}	4.870^{a}	0.12
80	Sp73	0.0464^{a}	3.751^{a}	0.91
	W73-74	0.0495^{a}	3.566^{a}	0.85
90	Sp73	0.0403^{a}	3.880^{a}	0.66
	W73-74	0.0604^{a}	3.866^{a}	0.97

*Sp73 = Spring 1973 series
W73-74 = Winter 1973-1974 series
S74 = Summer 1974 series
W74-75 = Winter 1974-1975 series

**Superscripts indicate statistical significance. See text for explanation.

TABLE 6. REGRESSION SLOPES, ELEVATIONS AND CORRELATION COEFFICIENTS FOR TOTAL COLIFORM COUNTS BY SEASON FOR VARIOUS TEMPERATURES. THE ELEVATIONS ARE GIVEN AS LOGARITHM TO THE BASE 10 OF THE BACTERIAL COUNT AND THE SLOPES ARE THE RATIO OF THE LOGARITHM OF BACTERIAL COUNT DIVIDED BY THE TIME IN HOURS SINCE THE TEST STARTED.

Temperature, °F	Season* and Year	Slope**	Elevation**	r
40	Sp73	$-.0057^{a}$	2.856^{ab}	-0.28
	W73-74	$-.0047^{a}$	2.172^{a}	-0.10
	S74	$.0057^{a}$	2.667^{b}	0.17
	W74-75	$-.0067^{a}$	2.350^{ab}	0.16
50	Sp73	$.0101^{a}$	2.581^{ab}	0.27
	W73-74	$-.0190^{a}$	3.286^{a}	-0.27
	S74	$-.0051^{a}$	3.862^{b}	-0.08
	W74-75	$-.0133^{a}$	2.738^{a}	-0.40
60	Sp73	$.0352^{a}$	2.941^{a}	0.39
	W73-74	$.0217^{a}$	2.702^{a}	0.30
	S74	$.0264^{a}$	2.506^{ab}	0.46
	W74-75	$.0005^{a}$	2.130^{b}	0.03
70	Sp73	$.0045^{ab}$	3.384^{a}	0.06
	W73-74	$.0558^{a}$	2.134^{a}	0.63
	S74	$.0387^{ab}$	3.281^{a}	0.91
	W74-75	$-.0004^{b}$	2.273^{b}	-0.01
80	S73	$.0272^{a}$	2.724^{a}	0.37
	W73-74	$.0494^{a}$	3.414^{b}	0.82
90	Sp73	$.0221^{a}$	2.116^{a}	0.50
	W73-74	$.0355^{a}$	4.122^{b}	0.83

*Sp73 = Spring 1973 Series
W73-74 = Winter 1973-1974 Series
S74 = Summer 1974 Series
W74-75 = Winter 1974-1975 Series

**Superscripts indicate statistical significance. See text for explanation.

TABLE 7. REGRESSION SLOPES, ELEVATIONS AND CORRELATION COEFFICIENTS FOR FECAL COLIFORM COUNTS BY SEASON FOR VARIOUS TEMPERATURES. THE ELEVATIONS ARE GIVEN AS LOGARITHM TO THE BASE 10 OF THE BACTERIAL COUNT AND THE SLOPES ARE THE RATIO OF THE LOGARITHM OF BACTERIAL COUNT DIVIDED BY THE TIME IN HOURS SINCE THE TEST STARTED.

Temperature, °F	Season and Year*	Slope**	Elevation**	r
40	W73-74	$.0129^{a}$	1.186^{a}	0.43
	S74	$-.0013^{a}$	3.975^{b}	-0.04
	W74-75	$.0119^{a}$	0.087^{c}	0.78
50	W73-74	$-.0062^{a}$	1.072^{a}	-0.20
	S74	$-.0221^{a}$	6.027^{b}	-0.38
	W74-75	$.0108^{a}$	0.562^{a}	0.33
60	W73-74	$.0243^{a}$	0.772^{a}	0.39
	S74	$.0099^{a}$	4.009^{b}	0.20
	W74-75	$-.0058^{a}$	0.603^{c}	-0.43
70	W73-74	$.0276^{a}$	1.540^{a}	0.32
	S74	$.0684^{a}$	3.460^{b}	0.69
	W74-75	$.0093^{a}$	$.998^{a}$	0.75

*W73-74 = Winter 1973-1974 Series
S74 = Summer 1974 Series
W74-75 = Winter 1974-1975 Series

**Superscripts indicate statistical significance. See text for explanation.

Correlation coefficients are also given in Tables 5, 6 and 7. These are very low except in the 80° and 90°F temperature tests. The S74 series also appears to have good correlation at 70°F for plate count, total coliform and fecal coliform. The W73-74 tests also tend toward increasing correlation beginning at the 70°F for total coliform. Low correlation coefficients indicate the relationship between bacterial count and time in the environmental chamber is not very strong.

Tables 8, 9 and 10 show the second analysis in which regression lines are fitted to data at each temperature within each seasonal series. The significant differences appear as superscripts as in Tables 5 through 7. For the plate count data, Table 8, only the 80^{o} and 90^{o}F tests differ significantly from the slopes of the other tests. Sp73, S74 and W74-75 total coliform slopes, Table 9, show no differences while the W73-74 tests show slightly different results. Slopes for the fecal coliform regression lines, Table 10, show no differences in the S74 and W74-75 series, while the W73-74 series show some variation between slopes for various temperatures.

Elevations for the curves in Tables 8, 9 and 10, although statistically significant, show no trends as might be expected since the elevations are measures of the predicted initial counts. Since the clams came from various locations, this irregularity might be expected. However, the W74-75 tests are an exception since there are no differences in initial counts for any temperature. Elevations are slightly different in Tables 5, 6 and 7 as compared to the same data in Tables 8, 9 and 10, respectively, because they are compared at a different time.

Since the first analysis, discussed above, showed essentially no slope differences between seasons for a given temperature, data from all four seasons were combined. The regression slopes (when the data is plotted as a straight line on a semilogarithmic plot), elevations and correlation coefficients for plate count, total coliforms and fecal coliforms are shown in Tables 11, 12 and 13, respectively. The slopes of the regressions for plate counts are not different for any of the four temperatures (i.e., 40, 50, 60, 70^{o}F) shown. This is equivalent to saying there is no detectable difference in bacterial growth rate between 40^{o} and 70^{o}F. This is probably due to the large variation in the data. There are significant elevation differences but no easily rationalized pattern is apparent. The exceedingly low correlation coefficients indicate the regression accounts for only a small part of the variation in the data.

TABLE 8. REGRESSION SLOPES, ELEVATIONS AND CORRELATION COEFFICIENTS FOR PLATE COUNTS BY TEMPERATURE FOR VARIOUS SEASONS. THE ELEVATIONS ARE GIVEN AS LOGARITHM TO THE BASE 10 OF THE BACTERIAL COUNT AND THE SLOPES ARE THE RATIO OF THE LOGARITHM OF BACTERIAL COUNT DIVIDED BY THE TIME IN HOURS SINCE THE TEST STARTED.

Season* and Year	Temperature, °F	Slope**	Elevation**	r
Sp73	40	$.0018^{a}$	4.279^{a}	0.09
	50	$.0016^{a}$	4.731^{b}	0.08
	60	$.0153^{ab}$	4.425^{ab}	0.62
	70	$.0026^{a}$	4.703^{b}	0.15
	80	$.0464^{b}$	3.751^{ab}	0.91
	90	$.0403^{b}$	3.880^{ab}	0.66
W73-74	40	$.0002^{a}$	3.651^{a}	0.01
	50	$.0021^{a}$	3.757^{ab}	0.16
	60	$-.0022^{a}$	3.846^{ab}	-0.11
	70	$.0183^{a}$	3.733^{b}	0.48
	80	$.0495^{b}$	3.566^{c}	0.84
	90	$.0604^{b}$	3.866^{c}	0.97
S74	40	$.0045^{a}$	4.169^{a}	0.22
	50	$.0048^{a}$	4.819^{b}	0.10
	60	$.0126^{a}$	4.379^{ab}	0.39
	70	$.0114^{a}$	4.956^{b}	0.81
W74-75	40	$-.0042^{a}$	4.901^{a}	-0.17
	50	$-.0090^{a}$	5.043^{a}	-0.43
	60	$.0110^{a}$	4.467^{a}	0.58
	70	$.0035^{a}$	4.811^{a}	0.12

*Sp73 = Spring 1973 Series
W73-74 = Winter 1973-1974 Series
S74 = Summer 1974 Series
W74-75 = Winter 1974-1975 Series

**Superscripts indicate statistical significance. See text for explanation.

TABLE 9. REGRESSION SLOPES, ELEVATIONS AND CORRELATION COEFFICIENTS FOR TOTAL COLIFORM COUNTS BY TEMPERATURE FOR VARIOUS SEASONS. THE ELEVATIONS ARE GIVEN AS THE LOGARITHM TO THE BASE 10 OF THE TOTAL COLIFORM COUNT AND THE SLOPES ARE THE RATIO OF THE LOGARITHM OF TOTAL COLIFORM COUNT DIVIDED BY THE TIME IN HOURS SINCE THE TEST STARTED.

Season* and Year	Temperature, °F	Slope**	Elevation**	r
Sp73	40	$-.0057^{a}$	2.856^{ab}	-0.28
	50	$.0101^{a}$	2.581^{ab}	0.27
	60	$.0525^{a}$	2.351^{ab}	0.54
	70	$.0045^{a}$	3.384^{a}	0.06
	80	$.0272^{a}$	2.724^{ab}	0.37
	90	$.0221^{a}$	2.116^{b}	0.50
W73-74	40	$-.0047^{ab}$	2.172^{b}	-0.10
	50	$-.0233^{b}$	3.040^{ab}	-0.34
	60	$.0256^{ab}$	2.474^{a}	0.33
	70	$.0487^{a}$	2.094^{ac}	0.53
	80	$.0494^{a}$	3.414^{c}	0.82
	90	$.0355^{ab}$	4.122^{c}	0.83
S74	40	$.0073^{a}$	2.587^{a}	0.22
	50	$.0129^{a}$	3.101^{ab}	0.17
	60	$.0264^{a}$	2.506^{ab}	0.46
	70	$.0535^{a}$	2.284^{b}	0.58
W74-75	40	$-.0067^{a}$	2.350^{a}	-0.16
	50	$-.0129^{a}$	2.725^{a}	-0.39
	60	$.0005^{a}$	2.130^{a}	0.03
	70	$-.0004^{a}$	2.273^{a}	-0.01

*Sp73 = Spring 1973 Series
W73-74 = Winter 1973-1974 Series
S74 = Summer 1974 Series
W74-75 = Winter 1974-1975 Series

**Superscripts indicate statistical significance. See text for explanation.

TABLE 10. REGRESSION SLOPES, ELEVATIONS AND CORRELATION COEFFICIENTS FOR FECAL COLIFORM COUNTS BY TEMPERATURE FOR VARIOUS SEASONS. THE ELEVATIONS ARE GIVEN AS THE LOGARITHM TO THE BASE 10 OF THE FECAL COLIFORM COUNT AND THE SLOPES ARE THE RATIO OF THE LOGARITHM OF FECAL COLIFORM COUNT DIVIDED BY THE TIME IN HOURS SINCE THE TEST STARTED.

Season and Year*	Temperature, °F	Slope**	Elevation**	r
W73-74	40	$.0129^{ab}$	1.186^{ab}	0.43
	50	$-.0062^{a}$	1.068^{a}	-0.19
	60	$.0243^{ab}$	0.772^{a}	0.39
	70	$.0277^{ab}$	1.535^{b}	0.32
	80	$.0568^{b}$	1.123^{b}	0.59
	90	$.0227^{ab}$	0.384^{a}	0.68
S74	40	$.0001^{a}$	3.819^{a}	0.00
	50	$-.0415^{b}$	6.398^{b}	-0.54
	60	$.0098^{a}$	4.009^{a}	0.20
	70	$.0304^{a}$	5.030^{b}	0.83
W74-75	40	$.0115^{a}$	0.091^{a}	0.79
	50	$.0108^{a}$	0.562^{ab}	0.33
	60	$-.0058^{a}$	0.603^{a}	-0.43
	70	$.0093^{a}$	0.998^{b}	0.75

*W73-74 = Winter 1973-1974 Series
S74 = Summer 1974 Series
W74-75 = Winter 1974-1975 Series

**Superscripts indicate statistical significance. See text for explanation.

TABLE 11. REGRESSION SLOPES, ELEVATIONS AND CORRELATION COEFFICIENTS FOR PLATE COUNTS BY TEMPERATURES USING DATA FROM FOUR SEASONS.

Temperature, °F	Slope	Elevation	r
40	$.0008^{a}$	4.139^{a}	0.03
50	$.0017^{a}$	4.487^{bc}	0.04
60	$.0067^{a}$	4.218^{ab}	0.18
70	$.0105^{a}_{*}$	4.443^{c}_{*}	0.30
80	NA_{*}	NA_{*}	-
90	NA	NA	-

*NA indicates data was not available for all four seasons.

The regression slopes and elevations for the combined total coliform data from all four seasons is shown in Table 12. The slope is the same in the tests at 40° and 50°F. The slopes for regressions on the 60° and 70°F tests are also not significantly different from each other. The negative slope (a reduction in growth rate with time) for the 50° and 60°F tests is probably a result of variation in the data and not to a true decline in count. The elevations for the regression lines indicate that only the 40°F test was different at time zero from any of the other tests. Again, the correlation coefficients are low for this data.

The fecal coliform data using tests from all seasons is shown in Table 13. The slopes are not significantly different for any temperature. The low correlation coefficients indicate fecal coliform growth is not closely related to temperature between 40° and 70°F in these tests. However, the correlation improves with increasing temperature.

TABLE 12. REGRESSION SLOPES, ELEVATIONS AND CORRELATION COEFFICIENTS FOR TOTAL COLIFORMS BY TEMPERATURE USING DATA FROM FOUR SEASONS.

Temperature, °F	Slopes	Elevations	r
40	$-.0004^{a}$	2.488^{a}	-0.01
50	$-.0077^{a}$	3.287^{b}	-0.12
60	$.0215^{b}$	2.682^{b}	0.30
70	$.0271^{b}$	2.783^{b}	0.36
80	NA*	NA*	--
90	NA	NA	--

*NA indicates data set was not available for all four seasons.

TABLE 13. REGRESSION SLOPES, ELEVATIONS AND CORRELATION COEFFICIENTS FOR FECAL COLIFORMS BY TEMPERATURE USING DATA FROM FOUR SEASONS.

Temperature, °F	Slope	Elevation	r
40	$.0055^{a}$	2.818^{a}	0.07
50	$-.0027^{a}$	2.387^{a}	-0.02
60	$.0202^{a}$	1.924^{a}	0.18
70	$.0428^{a}$	1.962^{a}	0.34
80	NA*	NA*	--
90	NA	NA	--

*NA indicates data was not available for all four seasons.

Discussion

Data from any set of tests run under the same conditions showed a wide variation. This is typical of bacterial data in general and is due to the fact that bacterial analysis measures the overall growth and reproduction of biological organisms (i.e., the bacteria). This variation does, however, limit the information which can be extracted from a data set.

Tables 11, 12 and 13 provide information in which as much of the variation as possible has been removed. Analysis as presented in Tables 8, 9 and 10 showed that harvesting season made essentially no difference in bacterial growth rate. Thus, data taken from four different time periods was combined. This increased the sample size and, hence, provided better parameter estimates for Tables 11, 12 and 13.

Generally, even after removing as much variation in the data as possible by statistical methods, the relationship between bacterial growth rate and storage time at constant temperature is either not a strong cause-and-effect relationship or the inherent variation in the data tends to mask the relationship. The low correlation coefficients in Tables 11, 12 and 13 are evidence of this. However, the increasing regression correlation coefficients with increasing temperature displayed in Tables 8 through 13 strongly suggest that the bacterial growth rate increases with temperature, but the increase in growth rate is not readily apparent as the temperature increases from 40° to 60° or 70°F. The inability to detect differences in bacterial growth rate between 40° and 50°F results from either actual lack of difference or, more likely, is due to the difference being masked by the variation in the data caused by uncontrollable factors. The inherent low precision in the bacterial analysis also contributed to these problems. It also appears that only in limited cases with the data available was it possible to detect a difference in bacterial growth rate in clams held at 40°F and those held at 70°F. Most of the time in this study, although not in all cases, it was possible to statistically show a difference in bacterial growth rate in clams held at 40°F versus clams held at 80° or 90°F when tests were continued over a 60 hour period.

Conclusions

1. When held under similar conditions for 60 hours there appears to be no difference in bacterial growth rate (plate count, total coliform or fecal coliform) in soft shell clams harvested in any of the seasons noted in these tests.

2. Generally, bacterial growth rate over a 60 hour period (plate count, total coliform and fecal coliform) is more closely related to time after harvest as the storage temperature increases from 40° to 90°F.

3. An attempt was made to correlate bacterial count (plate count, total coliform count or fecal coliform count) at harvest with harvest location, water temperature at the harvest location and/or water salinity at the harvest location. With the limited amount of data available, no correlations could be established.

4. Holding soft shell clam shellstock at 50°F or lower is sufficient to prevent a significant increase in plate count, total coliform count and fecal coliform count during a 60 hour storage period.

5. An increase in the plate count, total coliform count and fecal coliform count was observed in soft shell clam shellstock held at 60°F or higher for 60 hours. However, this increase may not be significantly different from the increase (slope) at lower temperatures for plate count and for fecal coliform count.

IV. COOLING METHODS FOR SOFT CLAM SHELLSTOCK

Introduction

Storage tests conducted with live clams indicated that growth of bacteria was halted at a temperature of 50°F or less (see Section III). Clams harvested during the warmer summer months were found to be at temperatures above 75°F and as high as 82°F while on board harvesting boats. During and after harvest ambient bay area temperatures above 80°F were common and were measured as high as 95°F. Current industry practice is such that clams can be on the boat and/or truck for up to 8 hours prior to placement in refrigerated storage. The cooling of clams at harvest was suggested as a means to eliminate this exposure to elevated temperatures and therefore reduce the potential for bacterial growth. Methods of cooling clams on the harvesting vessel were therefore examined.

There are several constraints to cooling on a clam boat. Available space is limited and location and size of open areas will vary with different boats. The only source of power is the internal combustion engine. The demand on the operator's time must be minimal and the clams, because of their fragile shells, should be cooled in the container into which they were placed at harvest. Cooling must be sufficiently rapid to keep pace with the harvest without freezing the clams. Excessive weight of the cooling system will result in longer travel times between dock and clam bottom, increasing the operating costs, and could lead to instability of the harvesting boat.

There are many potential cooling systems which might be used on board clam boats. Two of these, evaporative cooling and hydrocooling, have received limited study by other investigators. Evaporative cooling has been studied by Tatro et. al. (1967) to a limited extent, but due to the limited data taken, no definitive conclusions were reached. Work with evaporative cooling with poultry in the Salisbury, Maryland area indicate air temperatures can be lowered about 10°F at best (Felton, 1971). With 80°F plus air temperatures and a need to reduce clam temperatures below 50°F to stabilize bacterial deterioration, evaporative cooling appears to be impractical for the on-board cooling of clams.

Pumping bay water over the clams could also be used for temperature control. Unfortunately, summer water temperatures in the Chesapeake Bay are in the 70°to 80°F range every summer and some years exceed 80°F. This temperature is too high to retard bacterial growth in the clams.

Mixing ice with clams in the harvest basket will reduce clam temperature. However, there is a potential problem of short-changing the buyer at the time of transfer due to displacement of clams with ice. Because of this problem, mixing ice with the clams was rejected as impractical for cooling clams.

Hydrocooling is another potential cooling method. Wheaton (1971) investigated this technique for cooling clams. A spray device having the appropriate hole size and spacing was placed above a single bushel of clams. Water at a temperature of 36°F and a flow rate of 25-30 gpm was allowed to fall through the spray device onto and through the clams. In this manner clams with an initial temperature of 85°F were cooled to 40°F in 15 minutes. Required equipment included a refrigeration system, storage tank and pump. The continued use of recirculated water presented the possibility of bacteria buildup. Additional cooling equipment would be needed with this system to maintain a 45-50°F temperature after initial cooling. Hydrocooling, though effective, was felt to be unacceptable for use on board the relatively small boats used for dredging of clams, primarily because of size and weight of the water and equipment.

The research described herein utilized three types of cooling sources, three cooling systems and four container configurations. Ice, dry ice and mechanical refrigeration were used for cooling sources, the particular one used varying with the experimental setup as noted below. The three cooling systems tested were: a well insulated one bushel unit that depended on natural convection and conduction for heat transfer; a one bushel unit that used forced air circulation; and a six bushel forced air unit. The container configurations tested included a wooden bushel basket with no side openings; a wooden bushel basket with side openings as manufactured; a wooden bushel basket with openings modified to a uniform 1/2 inch in width; a round tapered wire bushel basket; and a rectangular wire container. The three cooling

systems are examined in the order in which they were designed and tested.

All tests of the cooling units were conducted in a 90°F ambient environment. In late summer this was accomplished by working outdoors. Temperature uniformity was not dependable so the testing was moved to a small boiler and steam room wherein pipe heat was supplemented with electric resistance heat. Requirements for additional space necessitated the construction of a controlled temperature chamber shown in Fig. 16. It consisted of a frame 12 feet long, 7 feet high and 6 feet wide covered inside and out with 4 mil clear polyethylene sheet. A 4 foot wide door in on end provided access. A thermostat ($\pm 1^{\circ}$F accuracy) controlled a 24 volt secondary circuit. This operated a 25 ampere relay which controlled a 1650 watt electric heater. Air circulation was provided by a small circulating fan located below the ceiling at the rear of the chamber. The amount of electrical resistance heat needed depended on the laboratory temperature and the type of cooling unit. The mechanical cooling produced sufficient heat that ventilation was required.

The majority of the clams used in the cooling studies were purchased from commercial watermen. Between tests the clams were kept in the one bushel holding tank with artificial salt water at 8-10°/oo and a temperature of 61-65°F. Clams were kept for periods up to several weeks and used repeatedly without feeding. No major change in appearance was noticeable nor was there any reason to suspect a change in the thermodynamic properties of the clams as a result of holding.

All temperature measurements were made with copper-constantan thermocouples inserted into the clam's body through the foot opening. This did not kill the clam but possibly caused internal injuries. The specific location of those clams into which wires were inserted depended on the unit under test. For the natural convective unit there were six measuring points per horizontal diagonal at three levels as shown in Fig. 17. Thermocouple location for the containers tested in the one-bushel forced air unit are presented in Fig. 18. The thermocouple locations for the containers tested in the six-bushel unit are presented in Fig. 19.

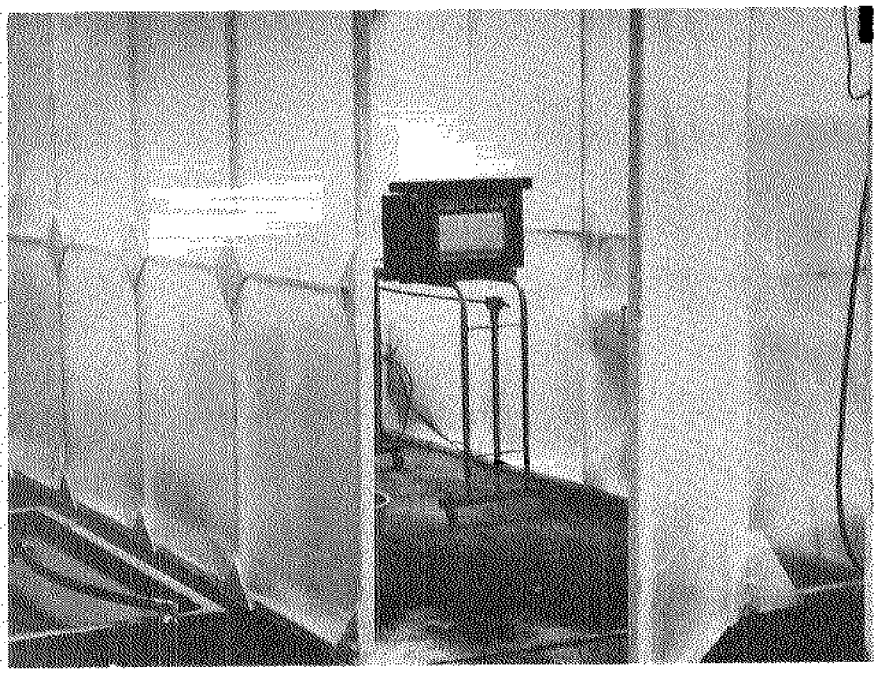

FIG. 16 Polyethylene covered controlled temperature chamber used to maintain 90°F.

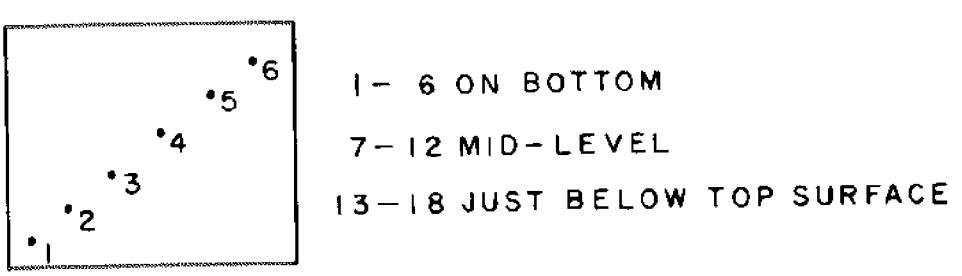

FIG. 17 Location of the 18 temperature measuring stations for the tests of the natural convective unit.

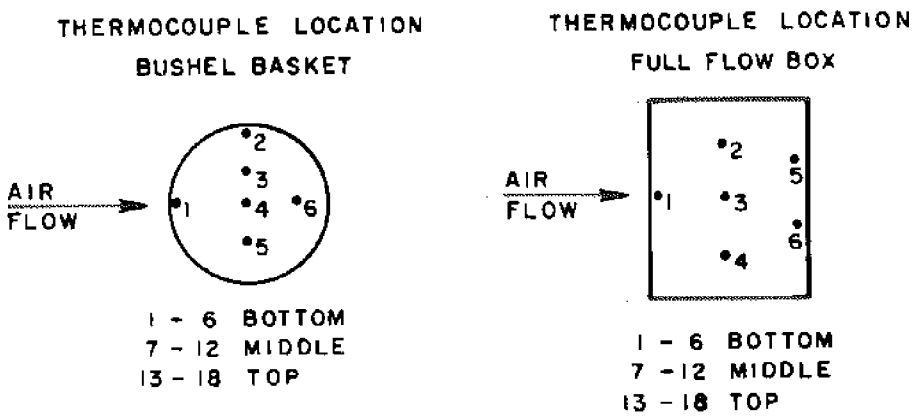

FIG. 18 Thermocouple locations for the four containers evaluated in the one-bushel cooling unit.

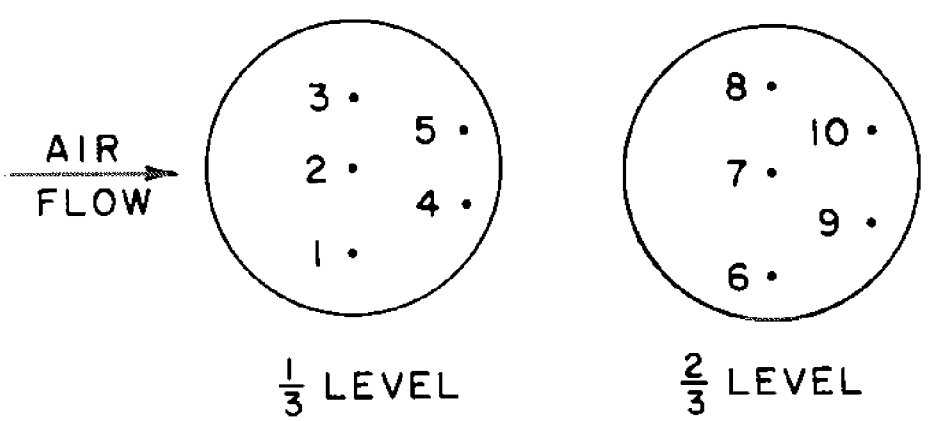

FIG. 19 Thermocouple locations for the containers tested in the six-bushel forced air unit.

Clams were removed from the holding tank and placed in the test baskets by hand. Any clams with cracked shells, limp siphons or other abnormal appearance were discarded. As the basket was filled, thermocouples were inserted into clams and these clams placed in the desired location within the basket. The full container of clams was warmed to as close to 80°F as possible in a tank of pre-warmed salt water, Fig. 20. The container was then placed in the cooling unit, the thermocouples connected to the recorder and the recorder cycled through all points to establish a temperature base line. Test duration depended on the cooling method and rate of cooling. Data for the two single bushel units was collected on a Texas Instruments 24 point strip chart recorder. Data for the six-bushel unit was collected on a Digitec 70 point digital print-out recorder.

One-Bushel Natural Convection System

This was the least complicated cooling system in that it required no moving parts. A box was constructed of an inner and outer shell of plywood with 2 1/4 inches of Styrofoam insulation between. The removable lid was of similar construction. The entire unit was coated with epoxy resin. Two different one-bushel containers were designed to fit into the plywood box. The first container had solid or nonperforated sides but a perforated bottom. The second container was constructed entirely of expanded wire mesh to allow air circulation through the four sides as well as the bottom. A perforated tray was designed to be supported by the container handles just above the clams to prevent direct contact between the clams and dry ice. Fig. 21 shows the plywood box, container (with nonperforated sides) and the dry ice tray. Fig. 22 shows the empty box. Fig. 23 shows the bushel container in position within the unit, while Fig. 24 shows the dry ice tray in position on top of the container.

Tests using dry ice as the cooling source were conducted only with the container having nonperforated sides. Ten pounds of dry ice were placed on the tray at the start of the test. The test duration was 5 hours, at the end of which time an average of 3 pounds of dry ice remained. Some frost appeared on those clams in the top layer and

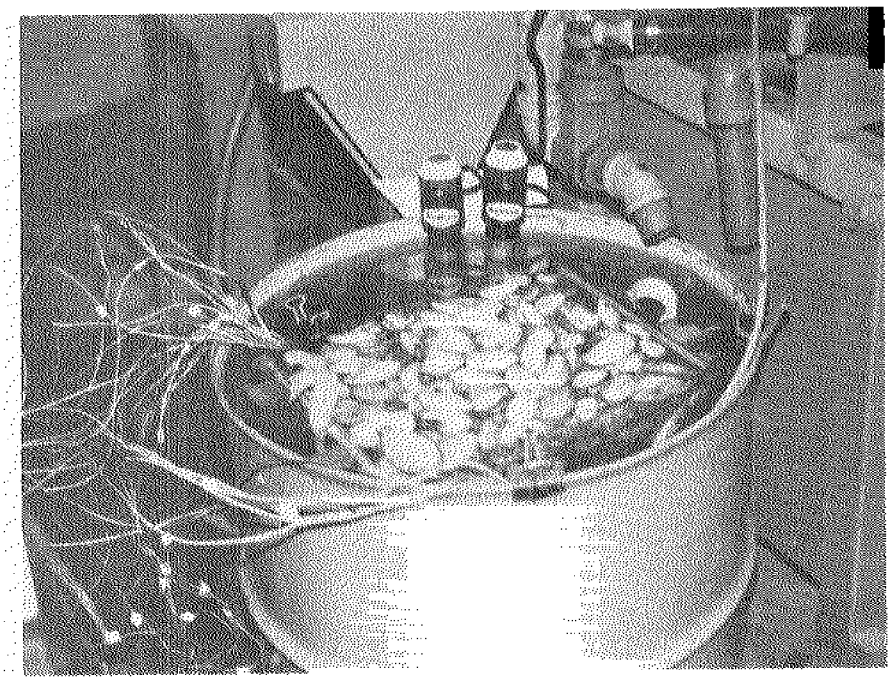

FIG. 20 Method of warming container and clams to 80°F.

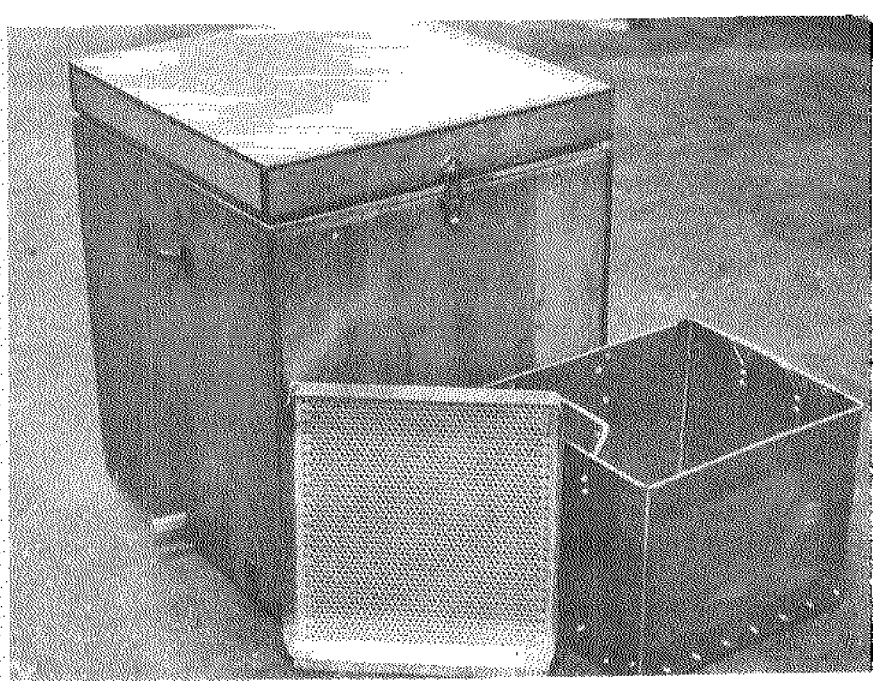

FIG. 21 Natural convection cooling system, nonperforated container and dry ice.

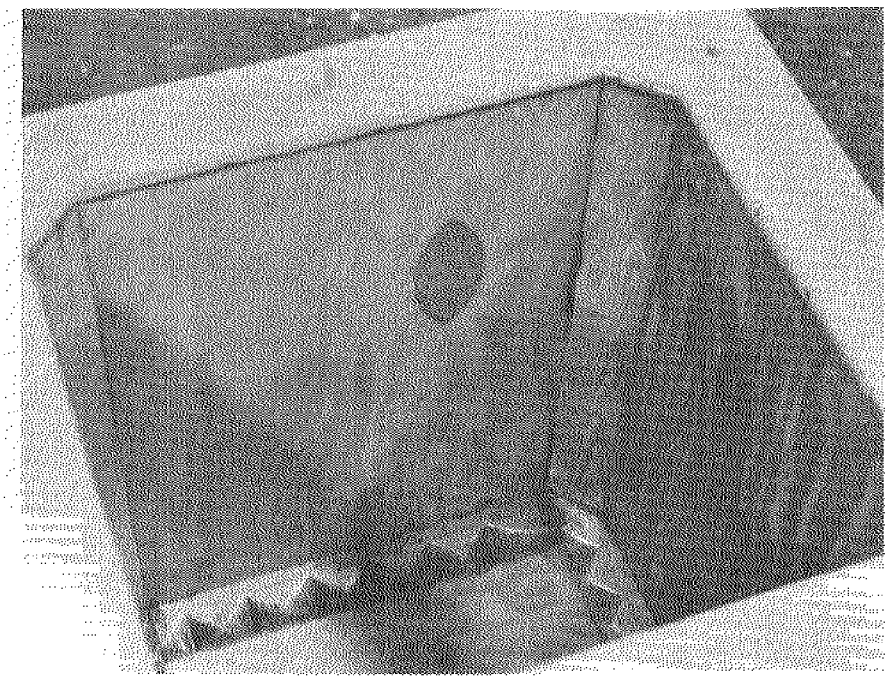

FIG. 22 Empty insulated plywood natural convection cooling box.

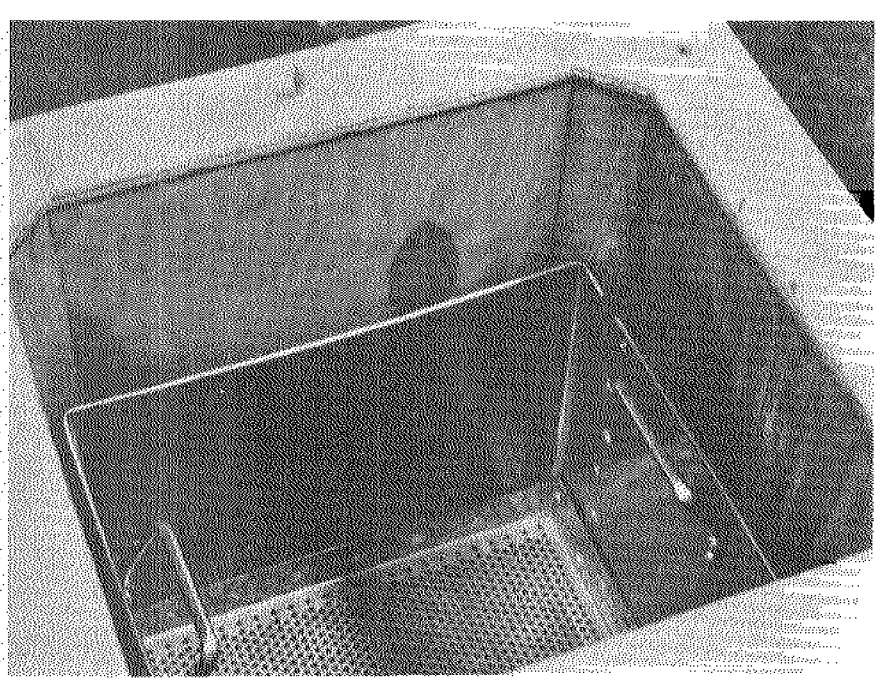

FIG. 23 Nonperforated bushel contained in natural convection cooling unit.

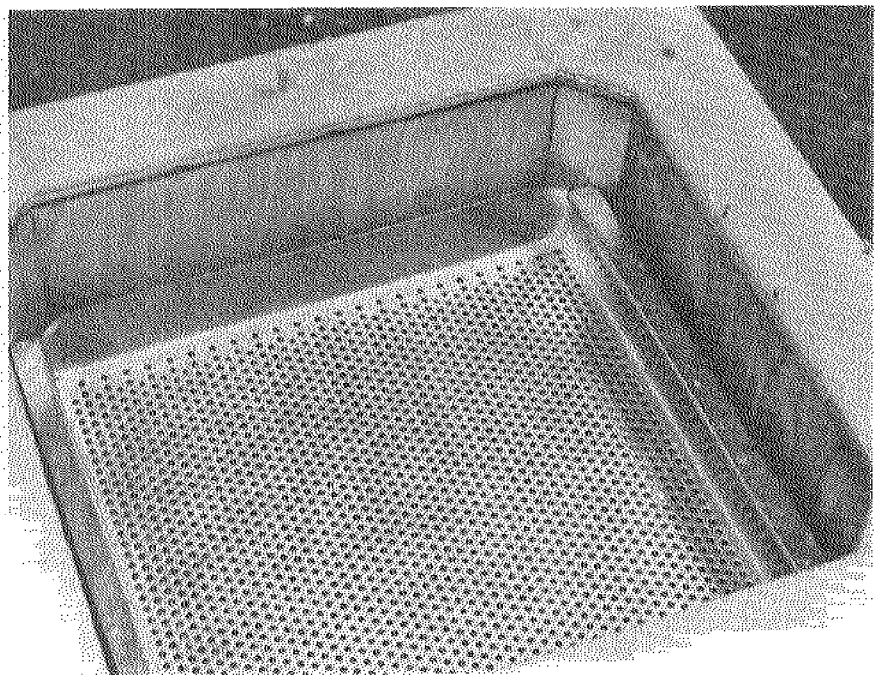

FIG. 24 Perforated tray used to keep dry ice above clams in the natural convection cooling unit.

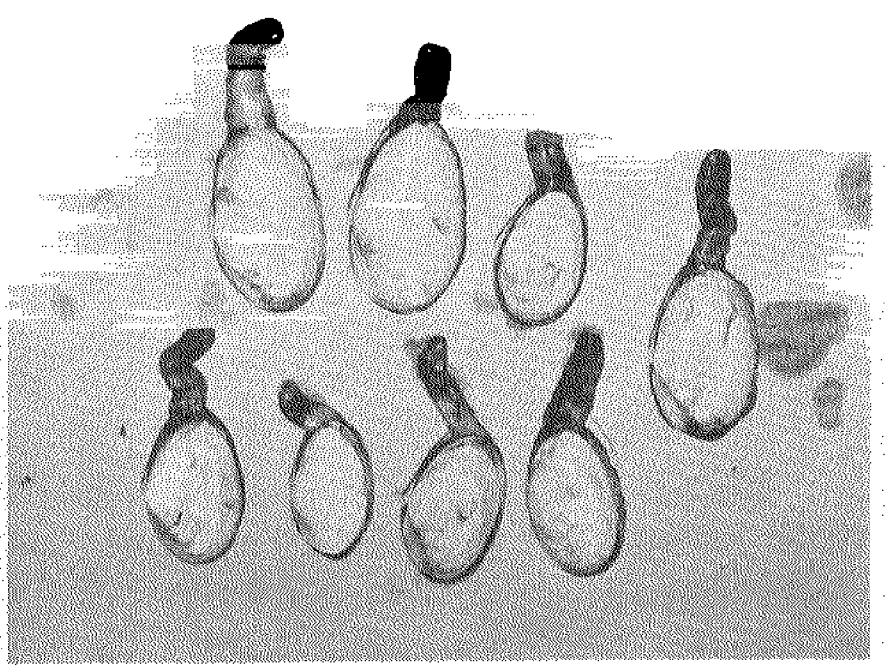

FIG. 25 Clams exhibiting very limp siphons after having been cooled for 5 hours with dry ice.

several were partly frozen. All of the clams exhibited very limp siphons (Fig. 25), possibly a result of the high concentration of carbon dioxide to which they were exposed. After a test, clams that had thermocouples inserted into them were discarded. The remainder were returned to the holding tank where no subsequent test related mortalities were observed within 20 hours.

Tests with ice were conducted without the use of the tray above the clams. The 27 pounds used per test was the maximum amount that could be placed in and around the container. Both the perforated and nonperforated containers were evaluated. A summary of test conditions and results is presented in Table 14.

TABLE 14. RESULTS OF COOLING CLAMS IN THE NATURAL CONVECTION UNIT WITH ICE AND DRY ICE AND TWO CONTAINER DESIGNS

Cooling source	Container	No. tests	Lbs. Material start	Lbs. Material used	Initial temp, deg F	Temp at 5 hrs, deg F	BTU per lb-deg F**
Dry Ice	A*	3	10	7	80.8	51.9	1.2
Ice	A	2	27	14	80.7	56.2	1.5
Ice	B	3	27	14	81.2	56.5	1.5

*Container A, nonperforated sides (see Fig. 21)
Container B, perforated sides

**BTU supplied by ice per lb of clams per degree F of cooling

The last column of the above table, BTU per lb-deg F, is based on a 55 pound net weight per bushel and values of 275 BTU per pound of dry ice used and 144 BTU per pound of ice used. The lower efficiency for ice is the result of three possible factors. Some of the ice was around the sides of the container so could melt and drain from the box without passing over the clams. Drain water had to be replaced with an equal volume of 90°F air. The sublimation of dry ice created a slight positive pressure within the box which prohibited infiltration of outside air through the entrance location of the thermocouple wires and through the drain. Inclusion of the heat absorbed in raising the temperature of the melt water above 32°F would tend to increase the value above 1.5 BTU/lb-°F.

Fig. 26 provides the cooling curves for the natural convection box tests. There appeared to be no difference in the cooling rate between the two container designs tested with ice. Rate of cooling with dry ice was slightly greater than for ice. The overall rate of cooling was slow relative to the total time the clams would normally spend on the boat and in transit. However, the use of cooling, even at this reduced rate, would eliminate the chance for an increase of clam temperature because of high ambient temperatures, and would reduce the total time required to cool the clams to an appropriate storage temperature.

One-Bushel Forced Air System

The relatively slow cooling rate provided by the natural convective system suggested a need for air circulation through the container to increase cooling rate. A unit containing a closed cycle circulation system was constructed of wood and plywood. The components included a blower compartment and Dayton model 2C970 blower, an ice storage compartment, a cooling compartment and a return air duct. The unit that evolved after several modifications is pictured schematically in Fig. 27. The original model was not insulated, had the blower drive motor within the box and had a rectangular ice compartment having a full cross sectional inflow and outflow screen (Fig. 28). When several tests demonstrated the workability of the system, the original unit was

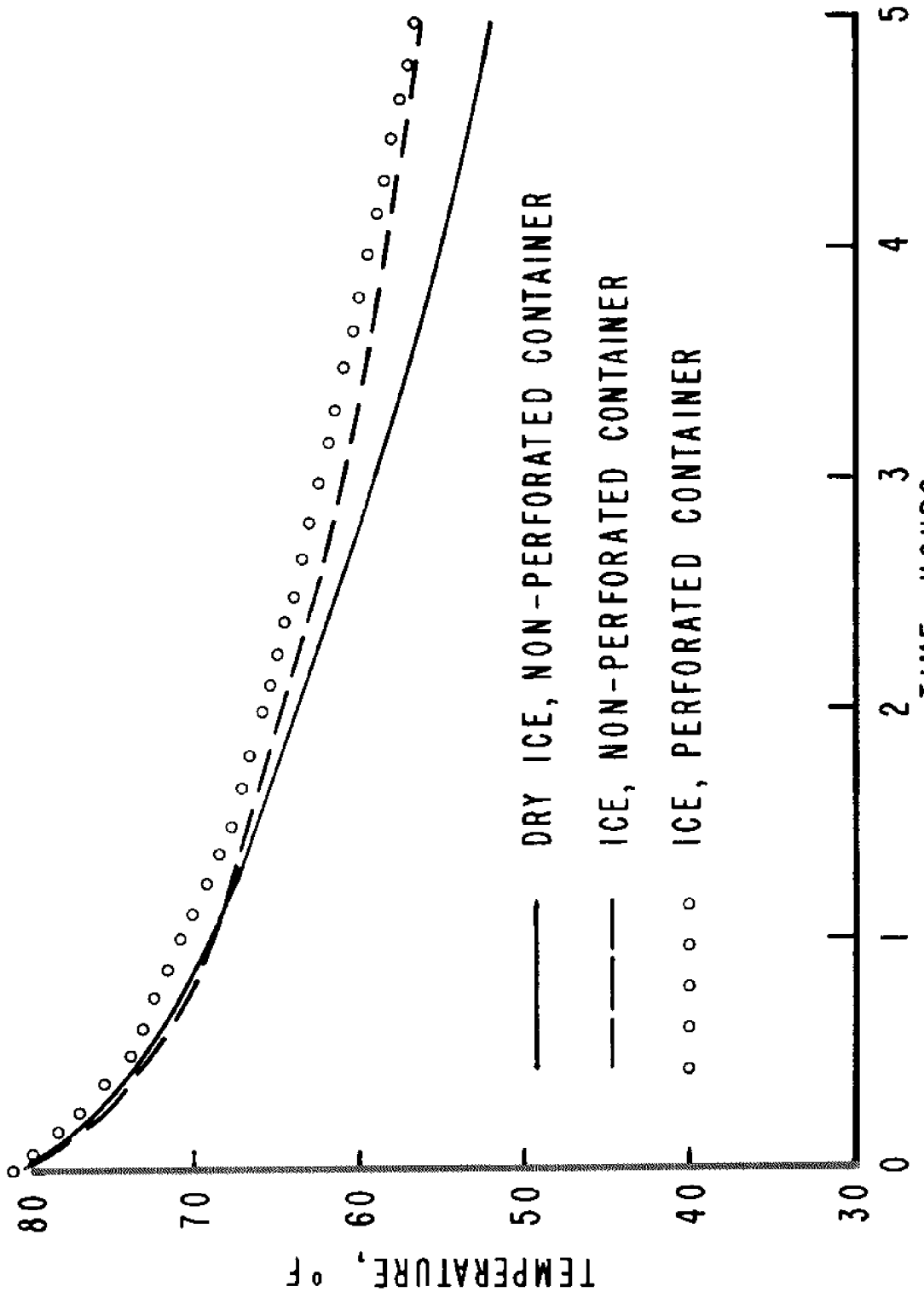

FIG. 26 Cooling rates for one bushel of clams in the natural convection unit using ice and dry ice and two container designs.

insulated with 3/4" of Styrofoam and an additional protective layer of 1/4" plywood. The fan drive motor was moved to the outside of the box (Fig. 29) to eliminate this heat load on the system and a hinged baffle (Fig. 30) was suspended from the ice compartment access lid to reduce bypassing of air above the ice. A series of tests was conducted with the original rectangular ice compartment. Initial ice melt allowed over-the-top bypass of air even with the baffle. Thus, the ice compartment was modified to the shape shown in Fig. 31 (also schematically in Fig. 27) for all remaining tests using ice and dry ice as the cooling source. This modification forced the air to pass through the ice before it got to the clams. The complete one bushel forced air unit is shown closed in Fig. 32 and with covers removed in Fig. 33.

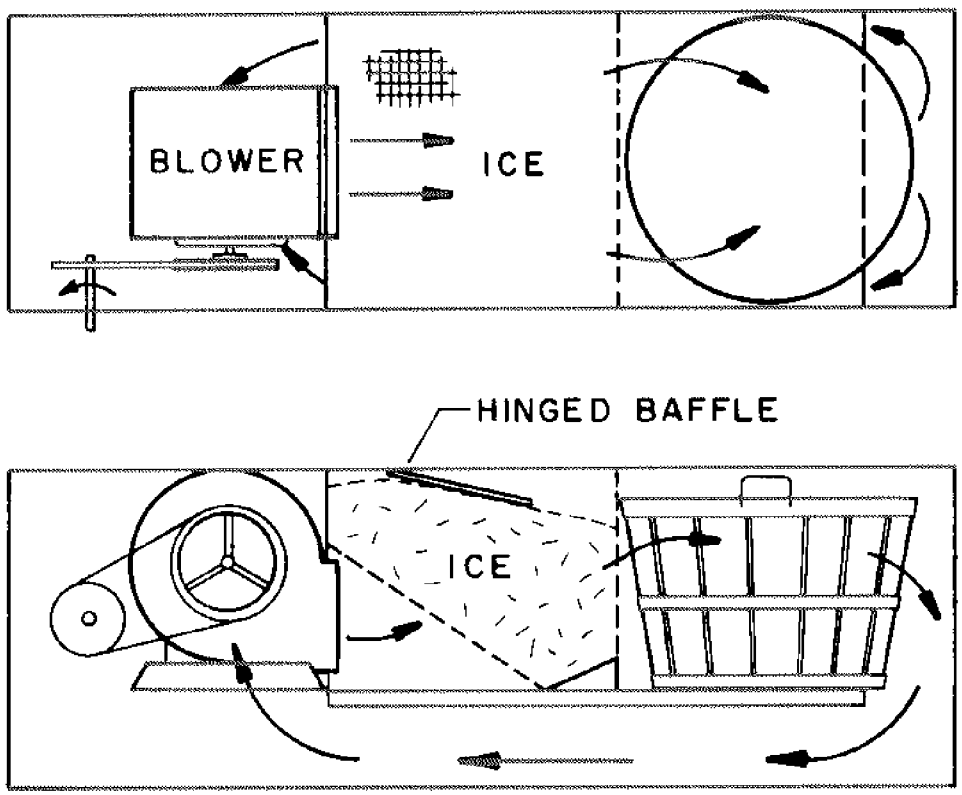

FIG. 27 Schematic of the one-bushel forced air cooling unit after several modifications.

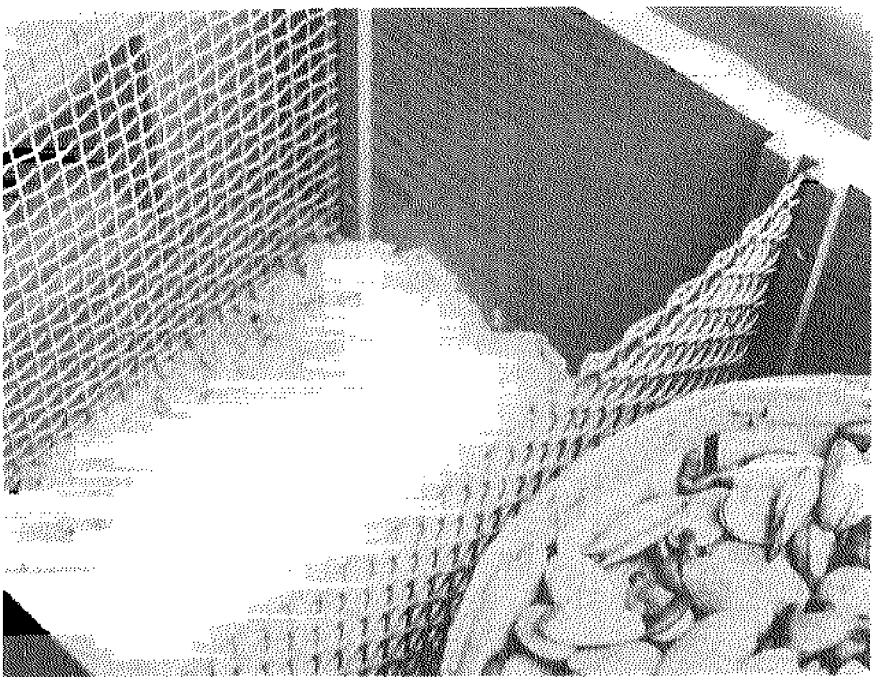

FIG. 28 Original rectangular ice compartment of one-bushel forced air cooling unit.

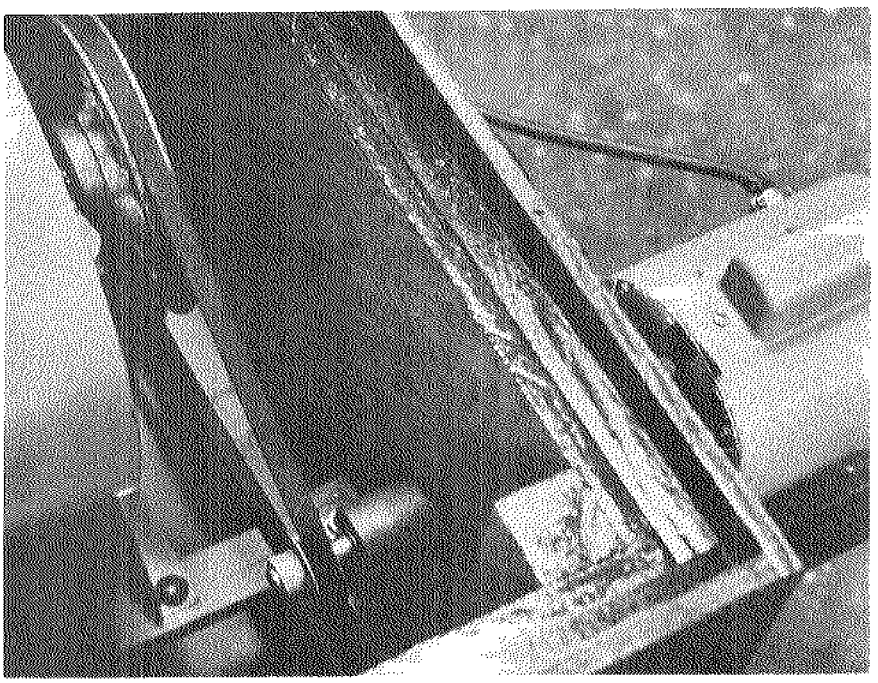

FIG. 29 Method of driving blower for the one-bushel forced air system.

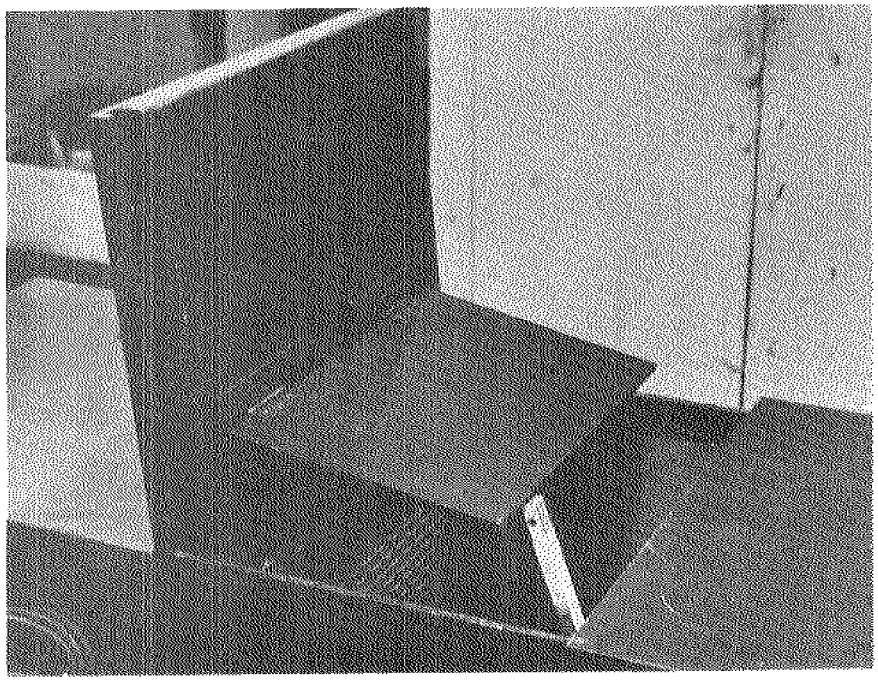

FIG. 30 Hinged baffel below ice compartment lid on the one-bushel forced air unit.

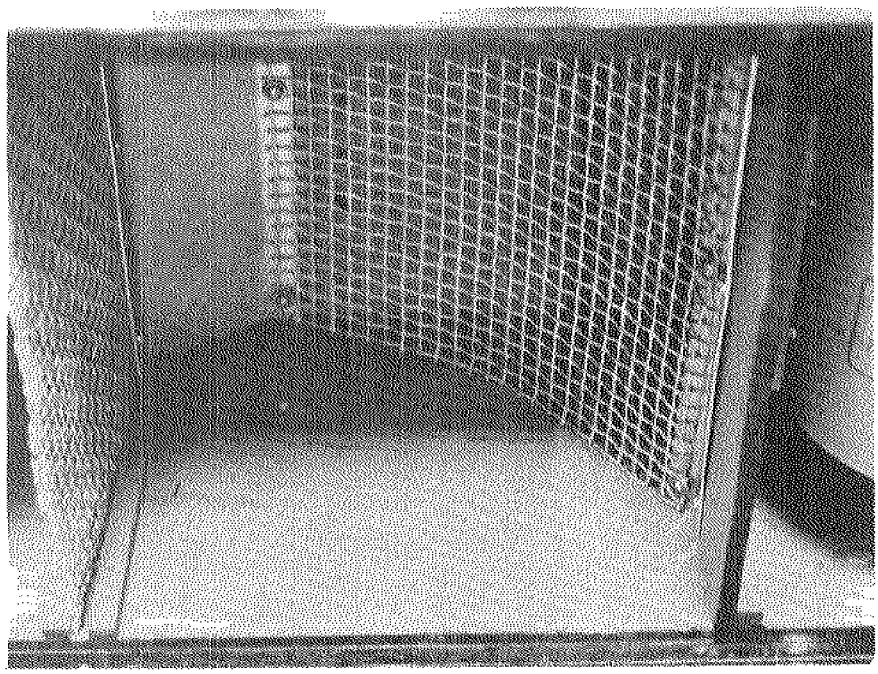

FIG. 31 Modified ice compartment, one-bushel forced air unit.

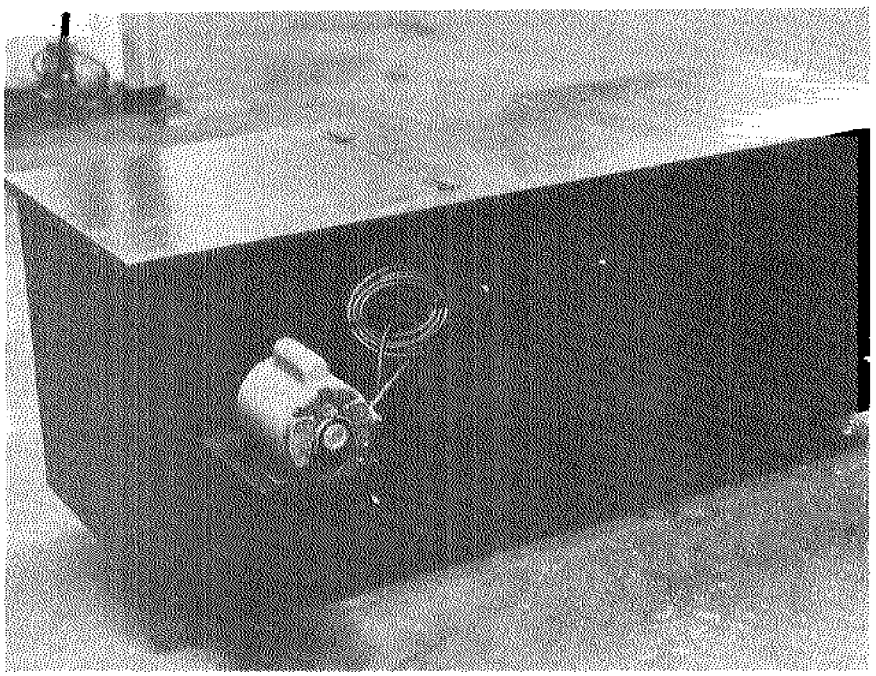

FIG. 32 One-bushel forced air cooling system.

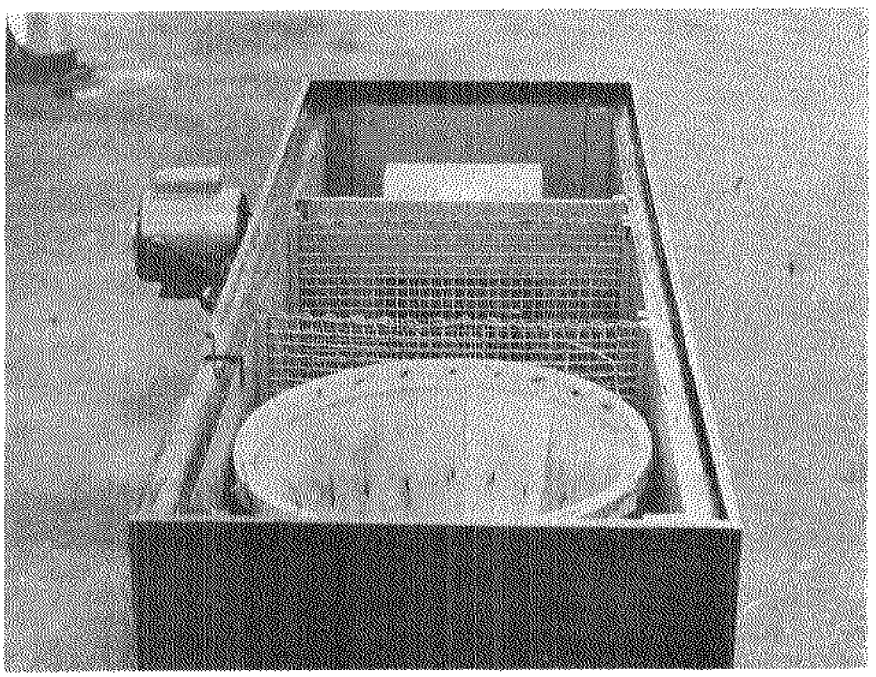

FIG. 33 Inside of one-bushel forced air cooling system.

Tests were conducted at two blower speeds. Initial tests with ice and dry ice were at a blower speed of 493 rpm (calculated from pulley sizes and known motor rpm). Additional tests with ice and all tests with the mechanical refrigeration system were conducted at a blower speed of 986 rpm. Blower speed is used as a relative measure of air flow because high turbulence prohibited accurate measurement of actual air flow in the relatively short duct.

Four container designs were used in testing the one-bushel forced air unit. Three had a tapered body and circular top as shown in Fig. 34. At lower right is the conventional wooden bushel basket with side openings comprising approximately 12% of the total side area of the basket. This basket, referred to herein as the open wooden basket, is presently used by the soft shell clam industry. At lower left is a wooden bushel basket manufactured with additional slatting and no open spaces on the side, herein referred to as the solid wooden basket. The third basket was constructed of stiff wire and provided an open side area of approximately 84% of the total side area. Fig. 35 (right) shows a container constructed from plywood and wire designed to fit the cooling chamber so that most of the cooling air was forced through the container of clams instead of over and around the container. It is referred to as the full flow container, and held the same volume as the other containers.

Results of the one bushel cooling tests provided relative rates of cooling as affected by: container design, blower speed, ice compartment design and cooling source.

Container Design

Container design had a significant effect on the rate of cooling. Fig. 36 presents the cooling curves for each of the four containers. The tests were conducted with the low speed blower using ice as the cooling source in the original ice compartment. The temperatures were established by averaging the values from all three levels but excluding the leading thermocouples (numbers 1, 7 and 13, Fig. 18), in order to get the "worst" condition.

FIG. 34 **Wire, solid wooden and open wooden bushel** containers evaluated in the one-bushel cooling unit.

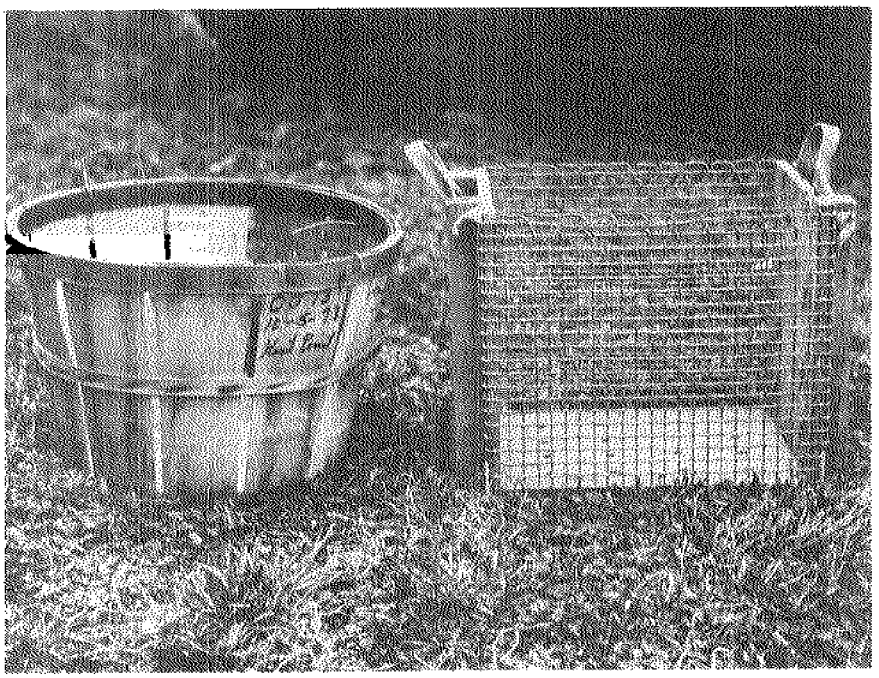

FIG. 35 Shop constructed full flow container (right).

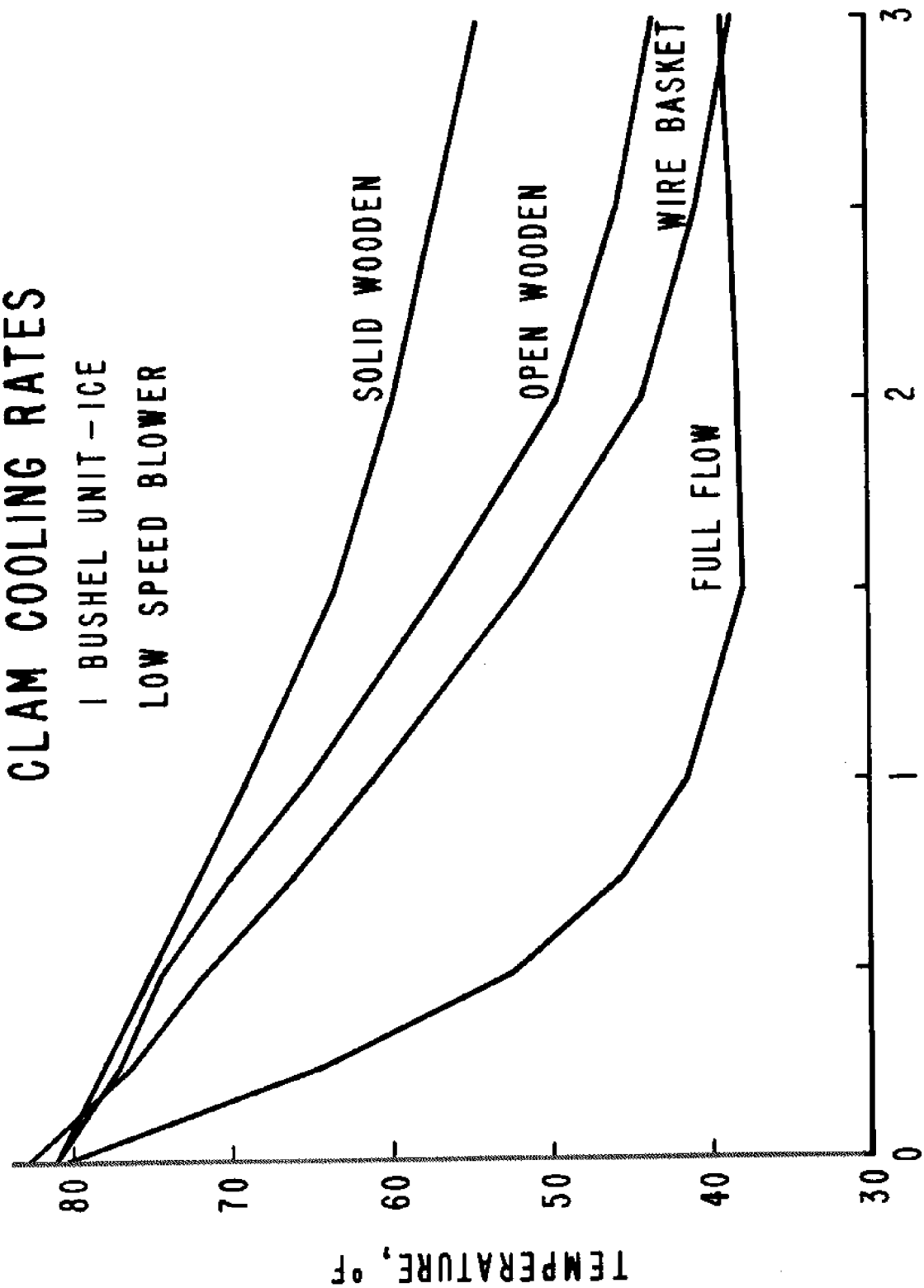

FIG. 36 Cooling rate for four different bushel size containers.

Rate of cooling for the solid wooden basket was sufficiently slow that an average temperature of 50°F was not realized within the 3 hour duration of the test. But compared to the natural convective unit previously discussed, the solid wooden basket was 9°F cooler after 3 hours of cooling. Rate of cooling for the open wooden and wire baskets improved in proportion to the openness of the side of the baskets. The tapered baskets were placed in a rectangular cooling chamber and no attempt was made to block air passing around the base of the basket. The cooling rate for the full flow container was superior to that of the three tapered containers and suggests that modification of the cooling chamber to reduce bypass could improve cooling for an open sided but tapered container. Table 15 provides a summary of the test conditions and average values for each set of tests.

The efficiency of ice utilization (Btu/lb-°F) improved in proportion to the openness of the side of those containers having a tapered configuration. Reduced efficiency resulted from use of the full flow container as a result of the greater resistance to air flow and the resultant increase of air leakage in and out of the cooling unit caused by the higher pressures.

TABLE 15. SUMMARY OF COOLING DATA FOR THE FOUR BUSHEL SIZE CONTAINERS COOLED WITH ICE AT THE LOWER BLOWER SPEED AND WITH THE UNMODIFIED ICE COMPARTMENTS

Container	No. tests	Lbs. ice start	Lbs. ice used	Initial temp, deg F	Time to 50°F, hr.	Time to 40°F, hr.	BTU per lb-deg F**
Solid wooden	3	51	36	81.4	NR*	NR	3.4
Open wooden	2	53	40	81.7	2.0	NR	2.7
Wire basket	2	52	37	83.3	1.6	2.6	2.1
Full flow	3	53	39	80.1	0.6	1.2	2.5

*NR - not realized during 3 hour test

**BTU from ice used per lb of clams per degree F

Blower Speed

The effect of blower speed on cooling rate was evaluated at the two blower speeds previously discussed. Results with the open wooden basket and the modified ice compartment are provided in Fig. 37. The upturn in temperature at 2 hours for the high blower speed is the result of having utilized all of the original 52 pounds of ice. Table 16 summarizes the data.

Air velocity was measured with an Alnor Thermoanemometer, the sensing probe of which was inserted into the return air stream. Accuracy of values is not assured due to the short length of the return air duct and the probability of turbulence. Of importance is the ratio of air velocities under the various conditions. The cross sectional area of the duct was 0.75 $ft.^2$ The ice utilization efficiency was calculated using temperatures at 2 1/2 hours and an estimated use of 38 pounds of ice for the test at the lower blower speed.

The reason for the more rapid utilization of ice at the higher blower speed was further investigated by conducting tests without clams. This provided an indication of "overhead" or ice utilized to reduce the temperature of the box and satisfy conductive and convective heat load. Tests were started with 52 pounds of ice. Low speed overhead was 26 pounds of ice in 3 hours. High speed overhead was 36 pounds in 2 1/2 hours.

Ice Compartment Design

The effect of ice compartment design on the cooling rate is shown in Fig. 38. Modification of the ice compartment resulted in more rapid cooling of the open wooden basket but had little effect for the full flow container. The reason for this difference is not known.

Cooling Medium

Dry ice was used in place of ice as a cooling source under forced air conditions. The 27 pounds of dry ice were selected for the initial loading to provide a BTU equivalency to 52 pounds of ice as follows:

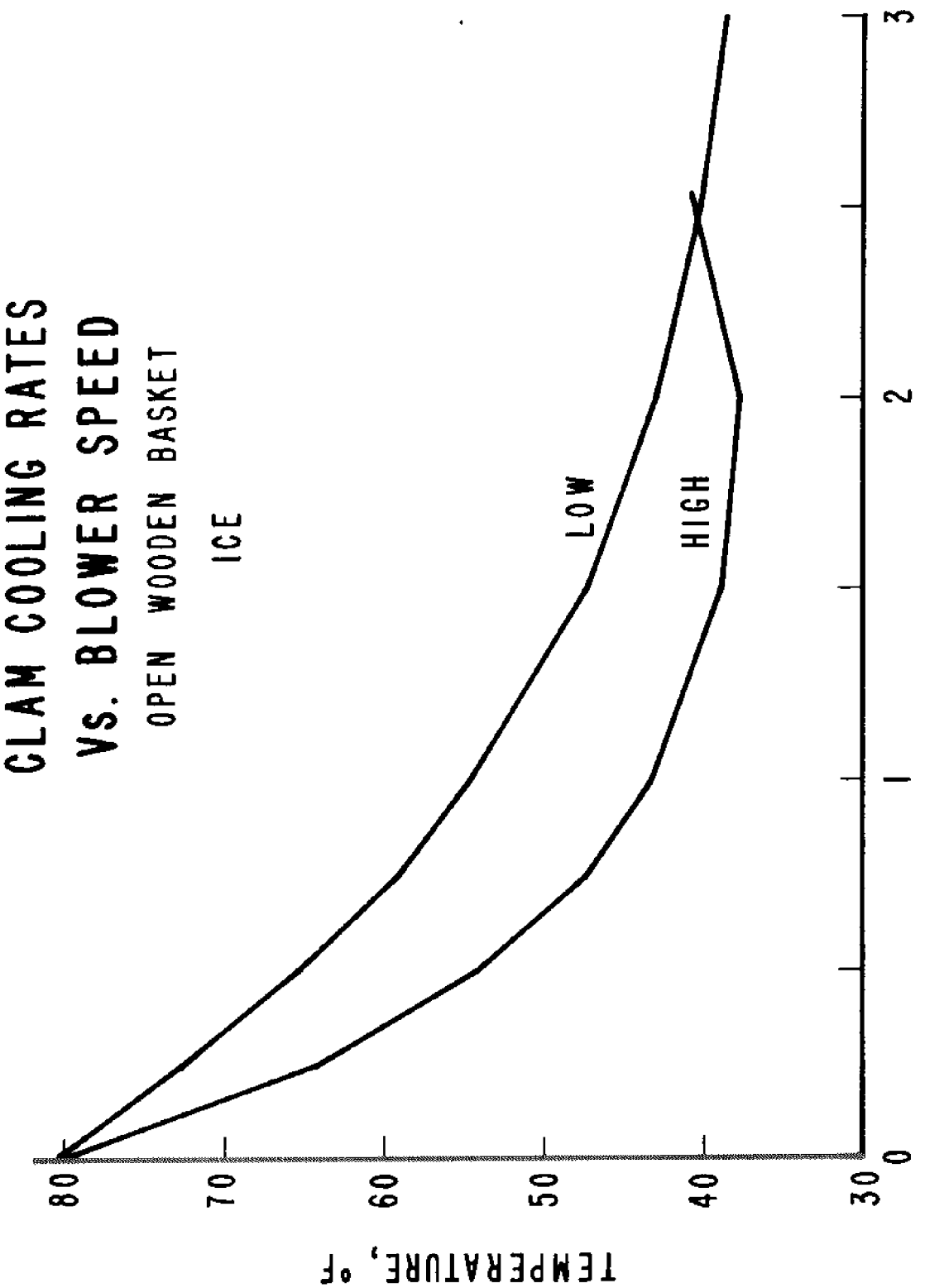

FIG. 37 Effect of blower speed on cooling rate with ice in the modified ice compartment.

TABLE 16. RESULTS OF COOLING THE OPEN WOODEN BASKET AT TWO BLOWER SPEEDS WITH ICE IN THE MODIFIED ICE COMPARTMENT

Blower speed	No. tests	Lbs ice start	Lbs ice used	Test duration, hr	Initial temp, deg F	Air vel, ft/min start	Air vel, ft/min end	Time to 50°F hr	Time to 40°F, hr	Btu per* lb-deg F
Low	3	52	40	3.0	80.6	220	500	1.3	2.6	2.4
High	3	52	52	2.5	80.2	525	1300	0.6	1.3	3.4

Note: Efficiency calculated at 2 1/2 hrs. assuming an estimated 38 pounds of ice used.

*Btu supplied by ice per lb of clams per °F temperature change

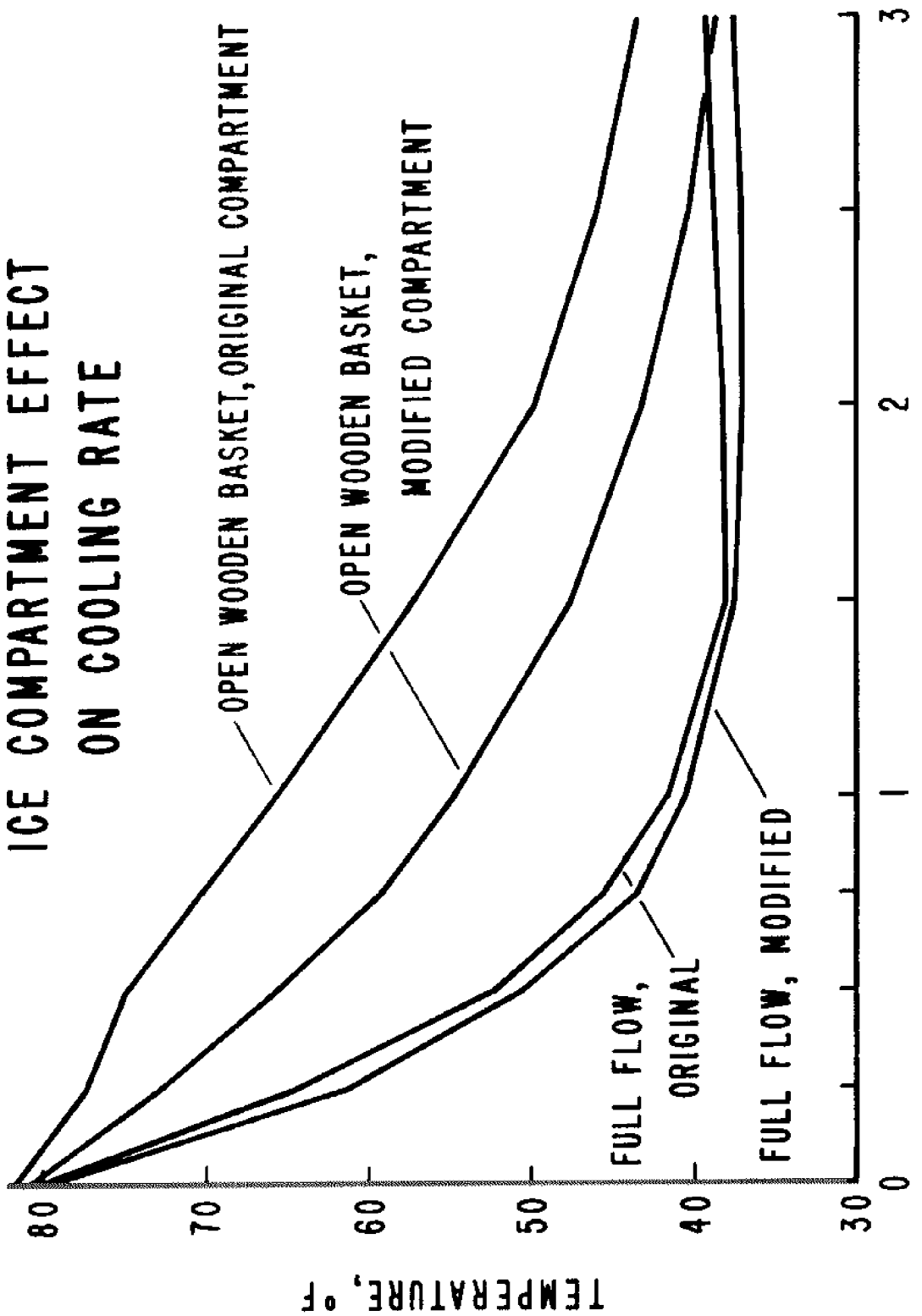

FIG. 38 Effect of modification of the ice compartment on the cooling rate of the open wooden basket and the full flow containers.

Dry ice sublimes at -109.3°F and requires 246 Btu/lb to do so. The specific heat of CO_2 gas at -94°F is 0.1870. The specific heat at 32°F is 0.1972. If these are averaged and multiplied by the temperature rise from -109° to 40°F an additional heat capacity of 29 Btu/lb is realized for a total dry ice heat capacity of 275 Btu/lb. The heat of fusion of water is 144 Btu/lb. The ratio of heat capacities of dry ice to ice is therefore 1.9 to 1 and 27 pounds of dry ice will be equivalent to 52 pounds of ice.

Comparative tests of ice versus dry ice were conducted with the open wooden basket in the modified ice compartment and low blower speed. The dry ice was broken into lumps no larger than three inches, since a previous test indicated a reduced cooling rate with a large single block of dry ice. Table 17 summarizes the results.

TABLE 17. COMPARISON OF COOLING RATES USING ICE AND DRY ICE, THE LOW SPEED BLOWER AND THE MODIFIED ICE COMPARTMENT

Cooling method	No. tests	Lbs Material start	Lbs Material used	Initial temp, deg F	Time to 50°F, hr	Time to 40°F, hr	Btu's used	Btu per* lb-deg F
Ice	3	52	40	80.6	1.3	2.6	5760	2.45
Dry ice	3	27	24.5	80.8	0.6	1.2	6737	2.38

*Btu's used per lb of clams per °F temperature reduction

A graph of the cooling rates (Fig. 39) shows that dry ice provided more rapid cooling than did ice. Table 17 indicates that more Btu's were expended by the dry ice but at the same efficiency as ice. At the beginning of the test, the full ice compartment acted as a restriction to air flow whereas the dry ice offered less restriction due to a smaller volume. The low sublimation temperature cooled the air to the 20-25°F range whereas ice cooled the air to a minimum of 32°F. Clam temperature readings of 29°F were recorded on occasion at the leading edge of the basket during the dry ice cooling tests. No freezing of clams was observed but with greater dry ice quantities and longer

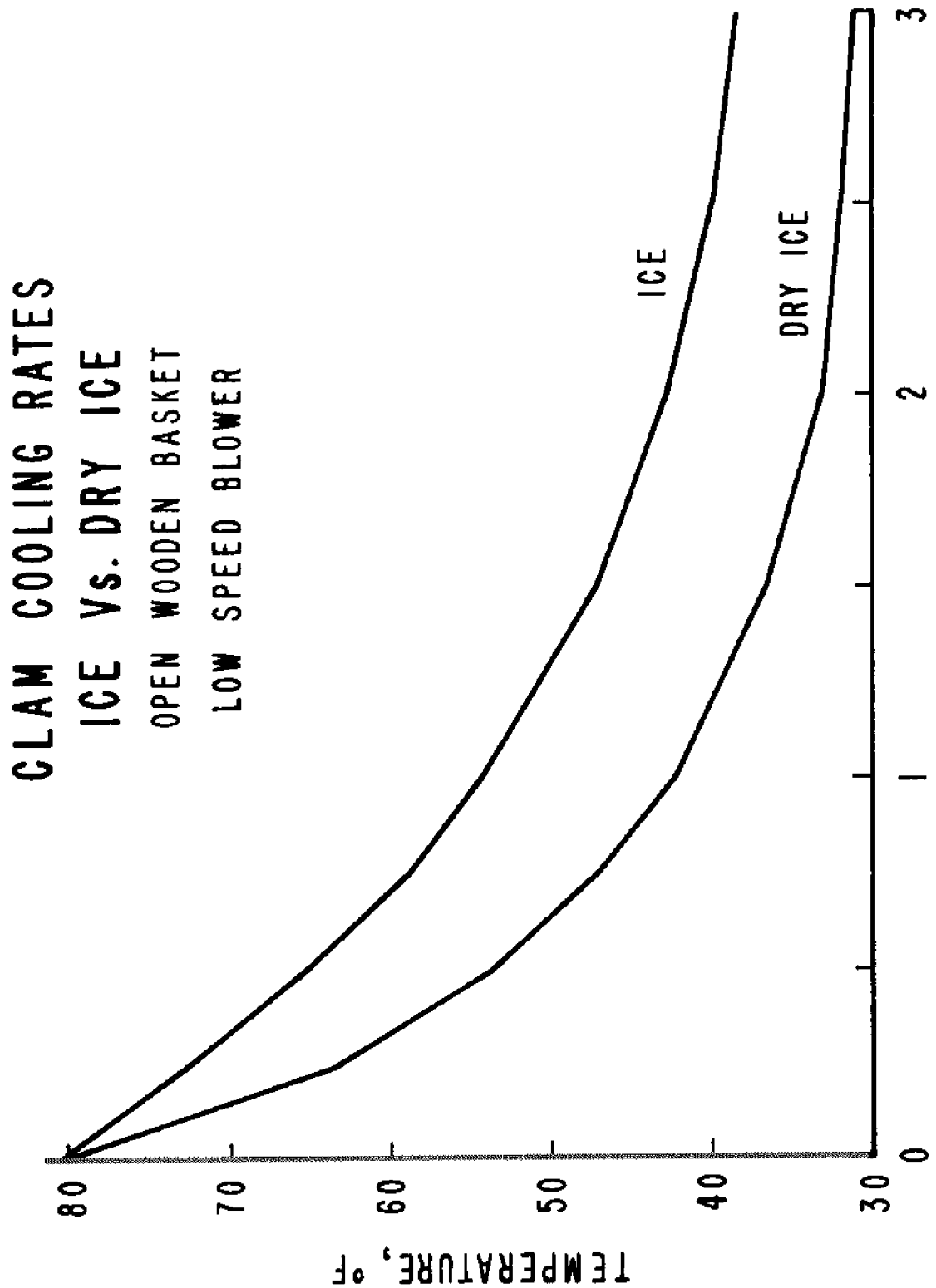

FIG. 39 Comparison of cooling rates for ice and dry ice using the modified ice compartment.

exposure times it appeared likely that some freezing might occur.

During testing in the plastic structure, CO_2 buildup was sufficient to cause eye and nasal irritation with as little as two minutes exposure. However, no ventilation of the chamber was provided and in open air as on a boat the CO_2 should not present any hazard. The clams did not appear as stressed in the forced air unit after the three hour test as they did after five hours of dry ice cooling in the static box.

One-Bushel Cooling System Using Mechanical Refrigeration

The use of mechanical refrigeration for on-board cooling has several advantages over the use of ice or dry ice. It is unnecessary to pick up ice and haul it to the harvest location. Also, no time is lost replenishing the cooling medium. Cooling is constant and unlimited. Disadvantages include high initial cost and possibly high maintenance cost depending on the operator's skill and knowledge of refrigeration equipment. Thus, because of the potential advantages, a mechanical refrigeration system was tested.

A used and disassembled automotive air conditioning system was acquired. The system was assembled by project personnel and included several additions to the original system. A second evaporator was added in parallel to the original one and a filter drier was installed prior to the expansion valve. A condenser fan was also added. The 12 volt DC requirement for the compressor clutch was met by a 12 volt storage battery, an automotive alternator and associated circuitry. A 5 hp, 3 phase electric motor provided power for the entire system.

The compressor, Fig. 40, a York model A209, 2 cylinder, 9 cubic inch, was designed for Refrigerant 12. The condenser fan first used was a 3 blade design (Fig. 41). For a fan speed of 1740 rpm a condenser temperature differential of only 12-20 degrees was achieved, while at 2400 rpm a temperature differential of 31 degrees was possible. The 3-blade fan at 2400 rpm was unsafe so a used 7-blade automotive fan was cut to size, balanced and installed (Fig. 42) in place of the 3-blade fan. Air direction was reversed in that the 7-blade fan pulled air through the condenser coil. A satisfactory condenser temperature differential of $38^{\circ}F$ was realized during testing.

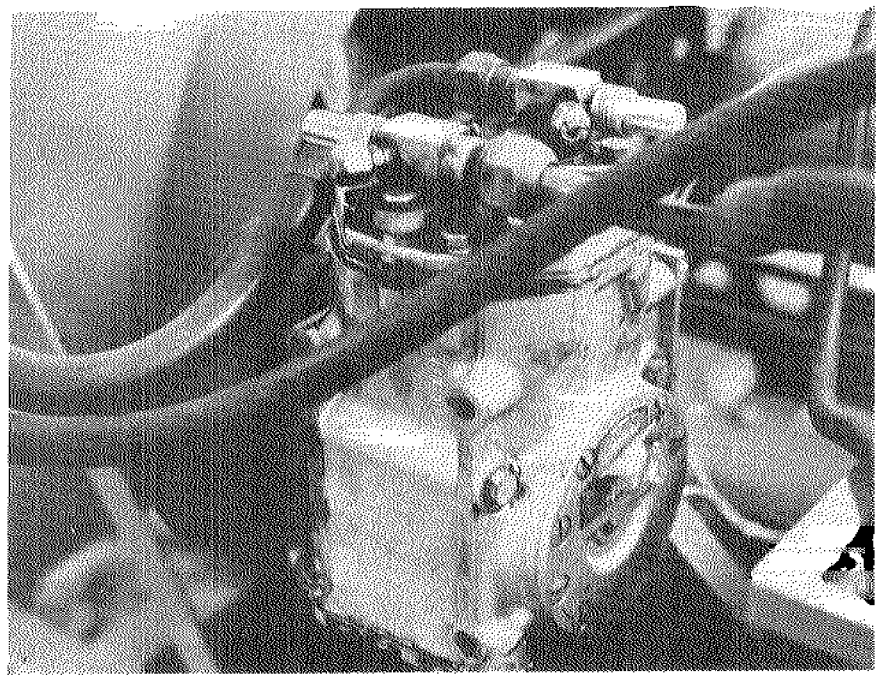

FIG. 40 York compressor used with the mechanical refrigeration system.

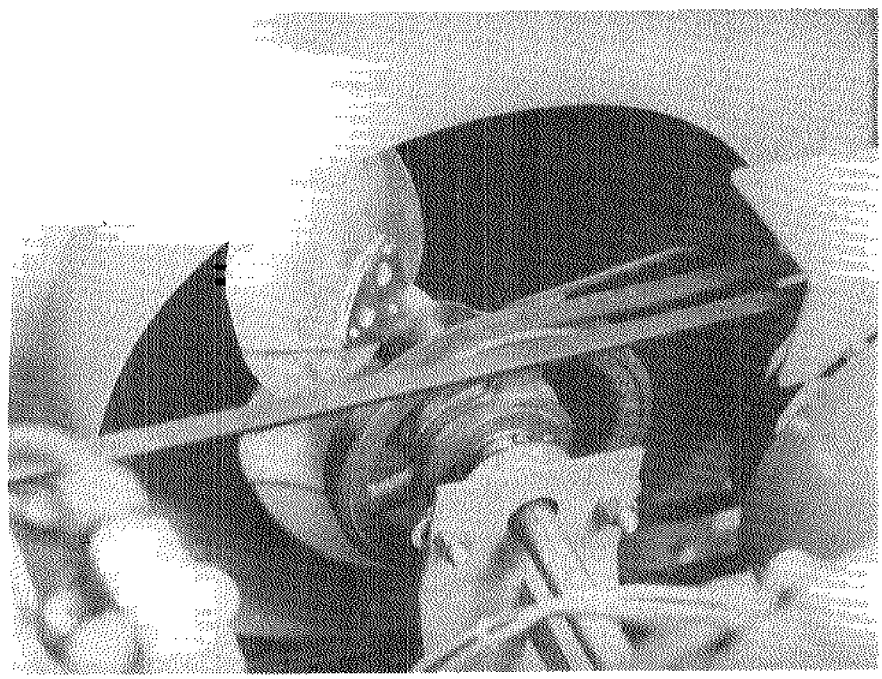

FIG. 41 Three blade condenser fan originally used in the mechanical refrigeration system.

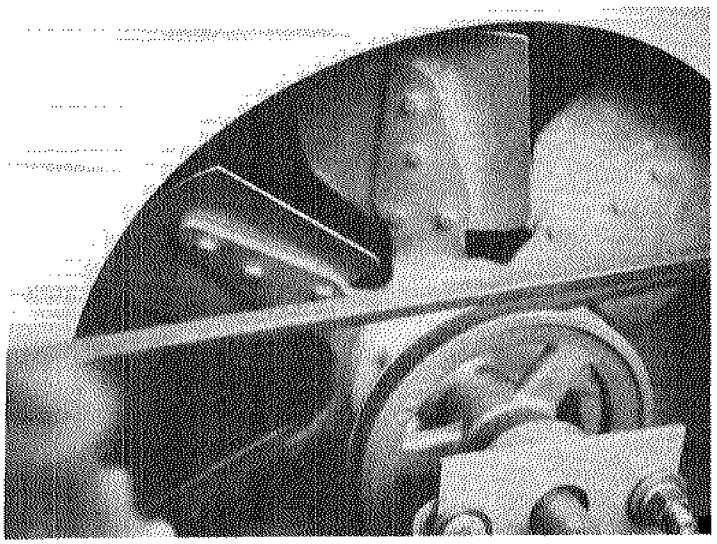

FIG. 42 Seven blade condenser fan used to replace the 3 blade fan.

Initial tests of the mechanical refrigeration system were conducted in conjunction with the one bushel forced air unit. Ice compartment screens were removed to provide room for the evaporator coil just downstream from the blower. No special effort was made to stop air from bypassing around the side of the evaporator.

Tests were conducted with the open wooden basket and the full flow container. The plastic temperature control chamber was used to maintain a 90°F ambient temperature. Clams were warmed to 80°F prior to testing as previously outlined. Blower speed was 986 rpm.

Frost formation was observed on the evaporator during operation. The original air conditioning system thermostat was installed downstream from the evaporator and off to the side. A section of rubber hose over the capillary tube reduced the time response of the thermostat and thereby reduced cycling frequency. The thermostat was adjustable by turning a control knob which was marked with "max, 4, 3, 2, 1" as indicators of temperature. Experience showed that some manipulation of the thermostat was needed to maximize the cooling rate without creating an icing condition on the evaporator or freezing of the clams. With the full flow container and a thermostat setting of 4, the clams were cooled to 33°F while at a thermostat setting of 4 1/2 they were cooled to 29°F. Tests with the open wooden basket were conducted at a thermostat setting of 4 1/2 with no indication of freezing. The restriction to air flow caused by the full flow container aggravated the evaporator icing problem. Tests with the full flow container were conducted at a thermostat setting of 4, and in addition the compressor was manually shut off for 45 seconds every ten minutes to defrost the evaporator.

The cooling rates for the open wooden basket and full flow container in the mechanically refrigerated system are presented in Fig. 43. A greater rate of cooling of the open wooden basket was achieved when compared to ice cooling at the same blower speed. Reasons for this included a greater air flow rate at the beginning of the test, a lower air temperature leaving the evaporator than leaving the ice and the continuous and consistant cooling provided by the evaporator. Table 18 provides the test results.

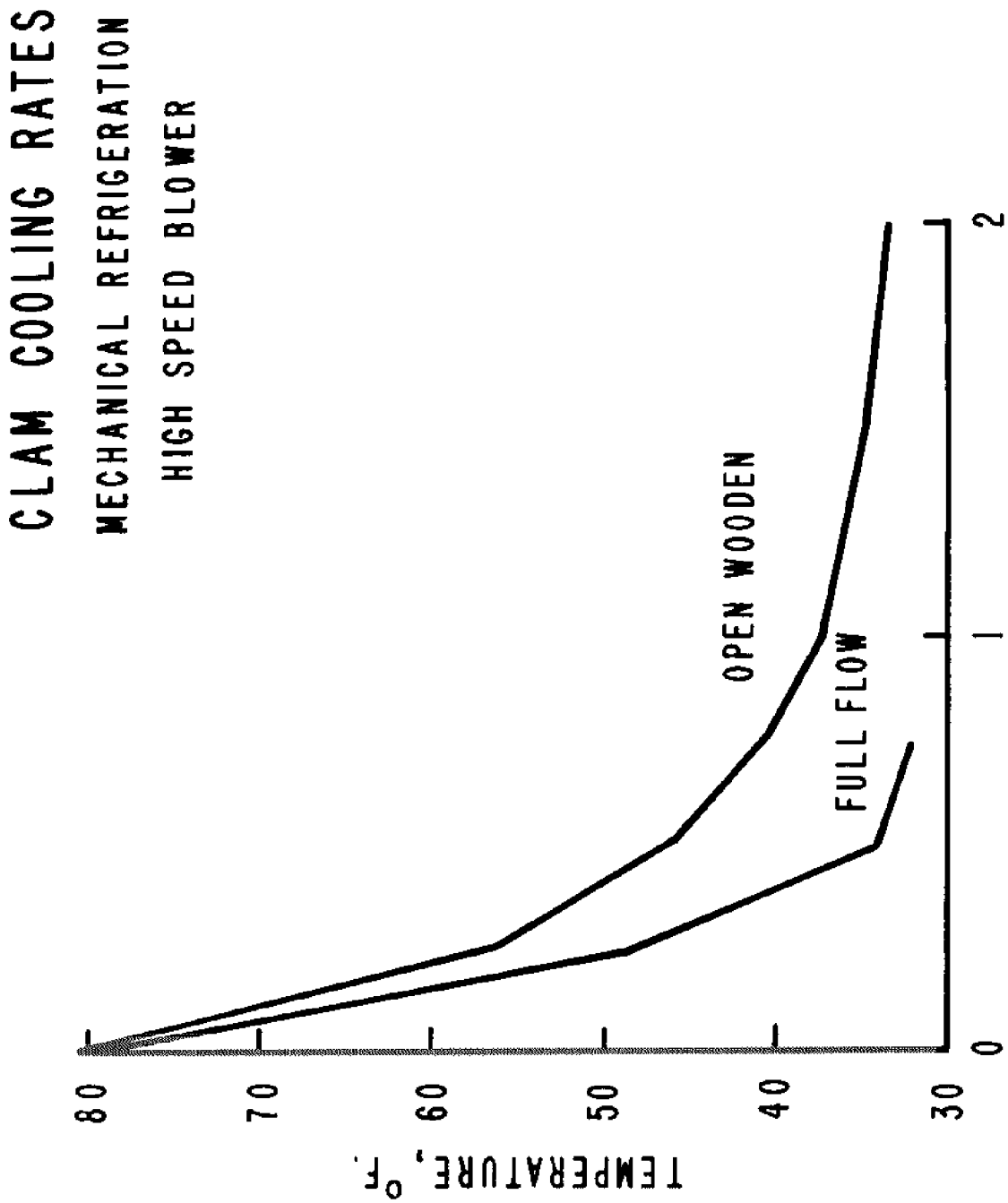

FIG. 43 Cooling rates using mechanical refrigeration for the open wooden and full flow containers.

TABLE 18. RESULTS OF COOLING TWO CONTAINER TYPES WITH MECHANICAL REFRIGERATION AT THE HIGHER BLOWER SPEED

Container	No. tests	Air velocity, ft per min	Test duration, hr	Time to 50°F, hr	Time to 40°F, hr
Open wooden	2	1300	2.0	0.4	0.8
Full flow	2	500	0.75	0.25	0.4

Cooling Gradients Within Baskets

Additional information on the nature of the cooling was obtained by plotting the temperature gradients through the middle level of the basket in the direction of air flow. Thermocouples number 7 through 12 provided this information. The air stream contacted the front of the basket at the location of thermocouple number 7. Through the center were numbers 8, 9, 10, 11 and at the back number 12. For the full flow container numbers 11 and 12 were at the back. Figs. 44-49 present the gradient data plotted every 1/4 hour for the first hour, then every 1/2 hour thereafter. At 1/4 and 3/4 hours the lines are dashed for clarity. "Front" refers to upstream (of airflow) side of the basket in Figs. 44-49.

Fig. 44 provides the gradient pattern for the solid wooden basket cooled with ice. The closeness of gradient lines reflects the relatively slow cooling rate exhibited. The rear of the basket cooled faster than the front. The center was the slowest to cool. The nature of the curves indicated conduction played a roll in the cooling of this type container. Fig. 45 shows the nature of cooling within the open wooden basket. Convective cooling of the front and center is indicated. Cooling rate of the back did not differ much from the solid basket. Fig. 46 is the cooling gradient plot for the wire basket, which demonstrated a consistent gradient from front to back. Cold air passing those clams at the front of the basket was warmed which thereby reduced its cooling effectiveness further downstream. Fig. 47 shows

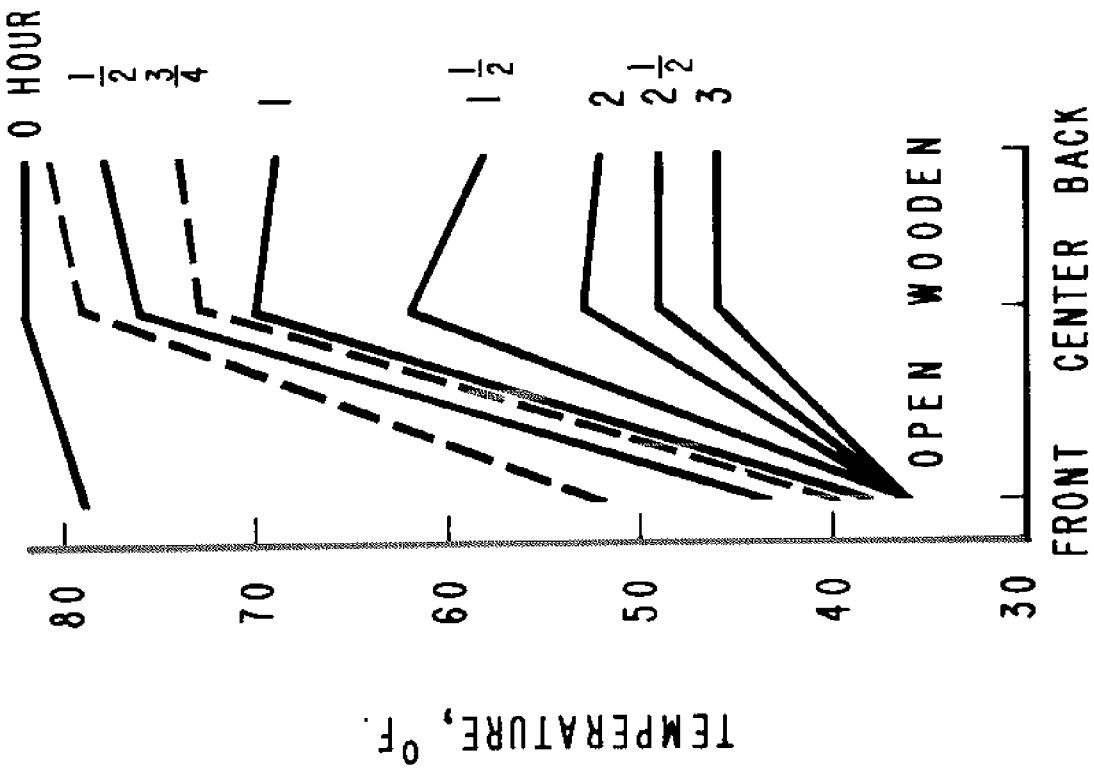

FIG. 45 Temperature gradients parallel to air flow. Open wooden basket cooled with ice.

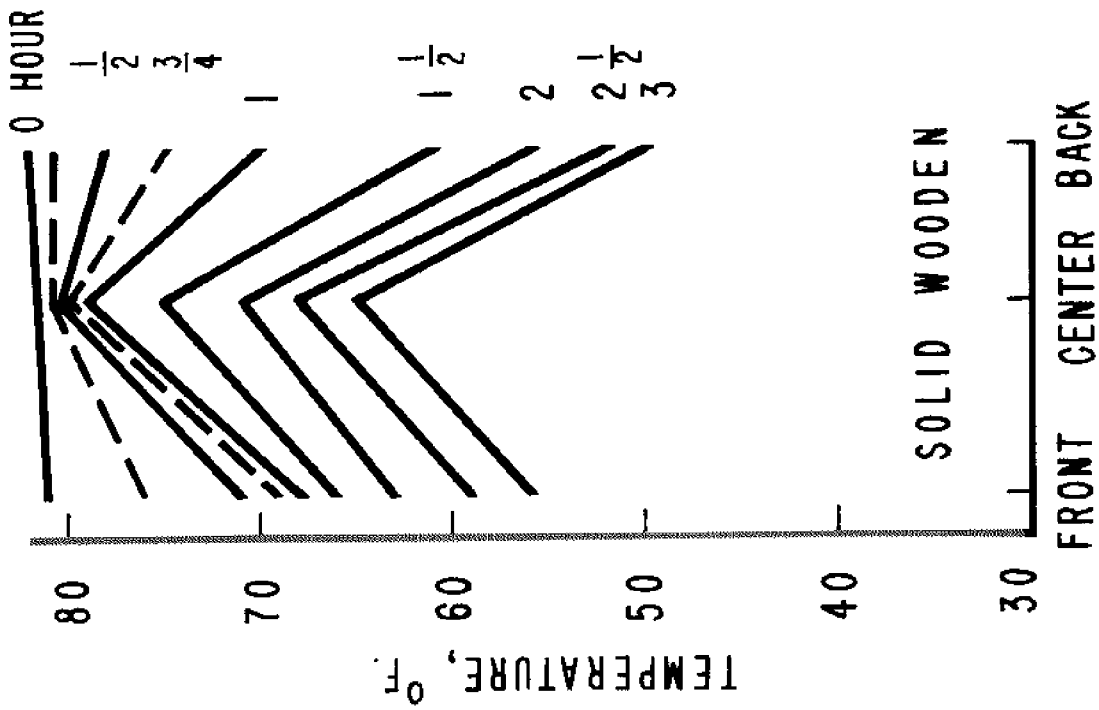

FIG. 44 Temperature gradients parallel to air flow. Solid wooden basket cooled with ice.

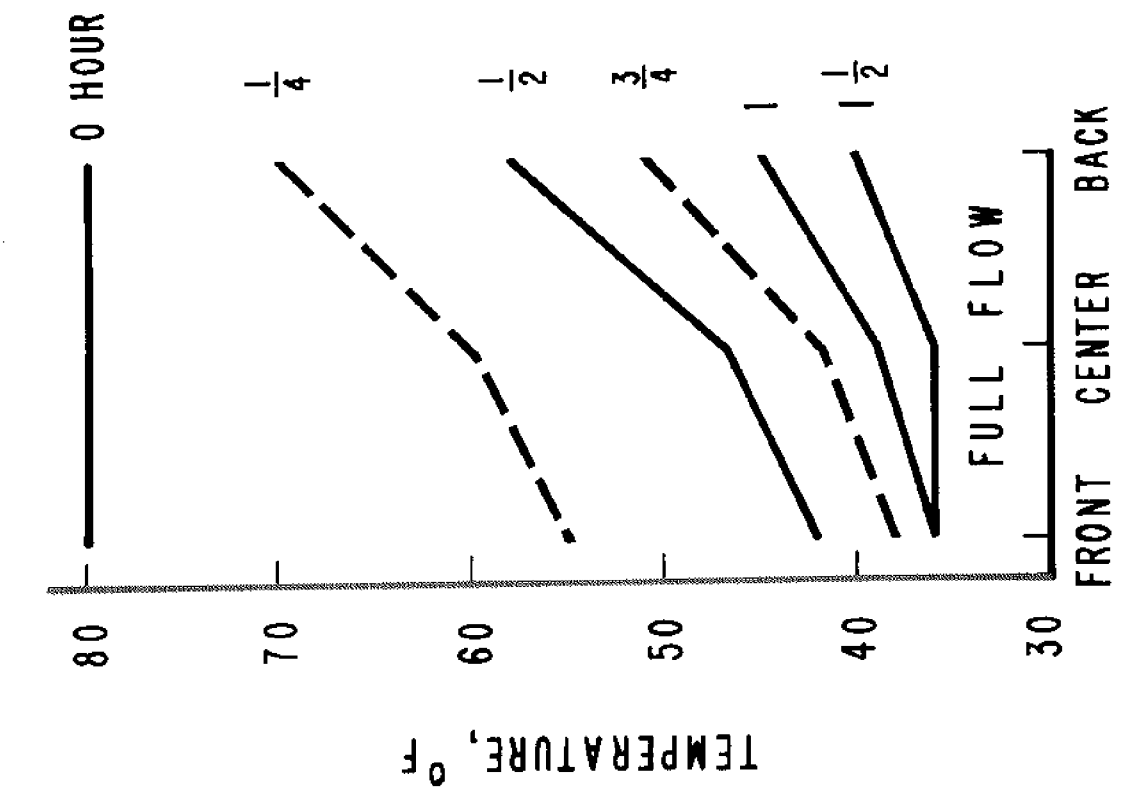

FIG. 47 Temperature gradients parallel to air flow. Full flow container cooled with ice.

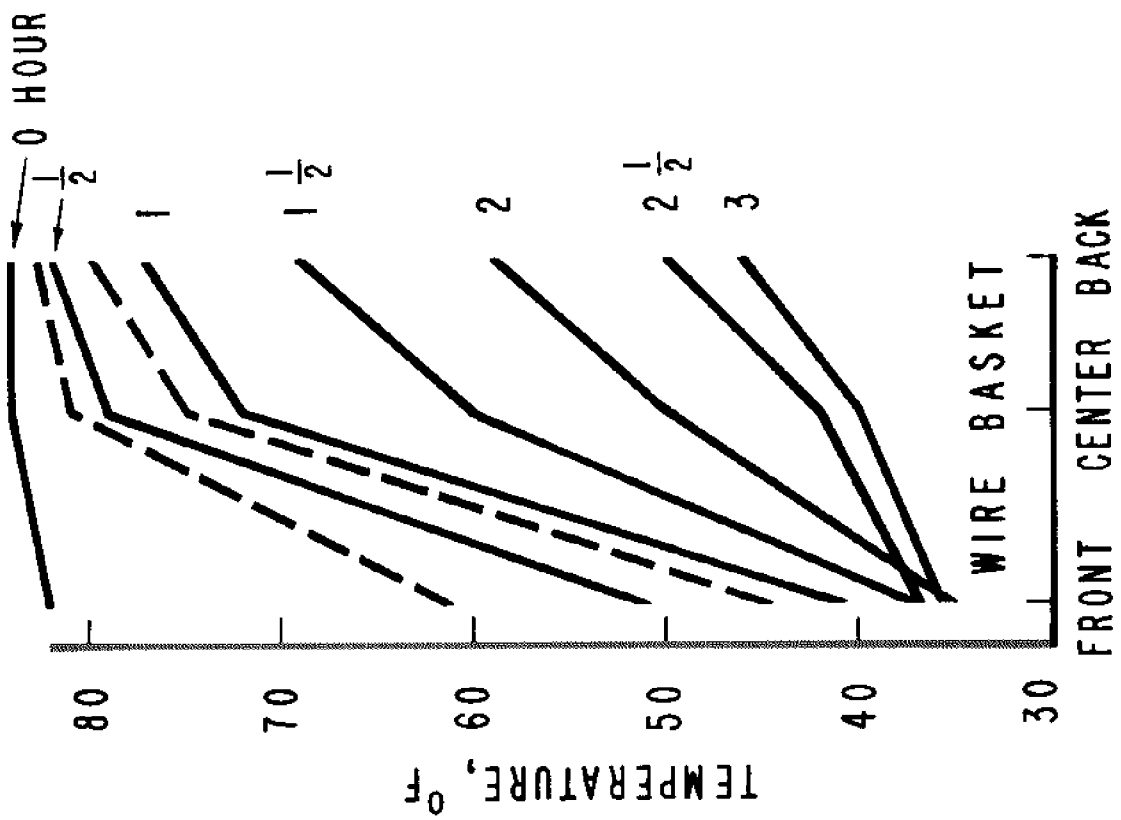

FIG. 46 Temperature gradients parallel to air flow. Wire basket cooled with ice.

the gradients for the full flow container cooled with ice. The flatter slope of the gradient lines indicated more uniform cooling, a result of higher air flow rates.

Fig. 48 provides the cooling gradients for the open wooden basket when cooled by mechanical refrigeration. The lower slope of the gradient curves compared to those of Fig. 45 is a result of the greater blower speed and the continuous full flow of air. Fig. 49 provides the cooling gradients for the full flow container cooled with mechanical refrigeration. The nearly horizontal gradient lines were the result of the high air volume passing through the container. This is the most desirable cooling of any shown in Figs. 44 through 49 since it lowered the temperature the most rapidly and the most uniformly.

Six-Bushel Forced Air System

The one-bushel forced air unit previously discussed served to evaluate container design, cooling source and air flow rate as factors in the cooling of clam shellstock. Commercial harvest involves the taking of a larger number of bushels as rapidly as both the resource and human ability allow. A harvest rate of six bushels per hour could be achieved with a dense population of large clams. A full seven hours of harvest time to take 15 bushels would more likely represent the usual harvest rate. For the purposes of testing, a harvest rate of 4 bushels per hour was selected. Once cooled, clam temperature has to be maintained. The holding of clams in the unit used for initial cooling eliminates the need for transfer labor as well as the need for a second unit. The current legal harvest is 15 bushels per day. A unit of this capacity would have been expensive to build and evaluate. Since a six-bushel unit was the smallest sized unit which could adequately simulate commercial harvesting operations, a unit of this size was constructed.

Fig. 50 shows the six-bushel unit with the mechanical refrigeration system installed. The unit was designed for two rows of three bushels each. The original system incorporated a set of baffles for air flow control and an underfloor plenum system for air return. The same blower was used as in the one-bushel unit, but the blower was

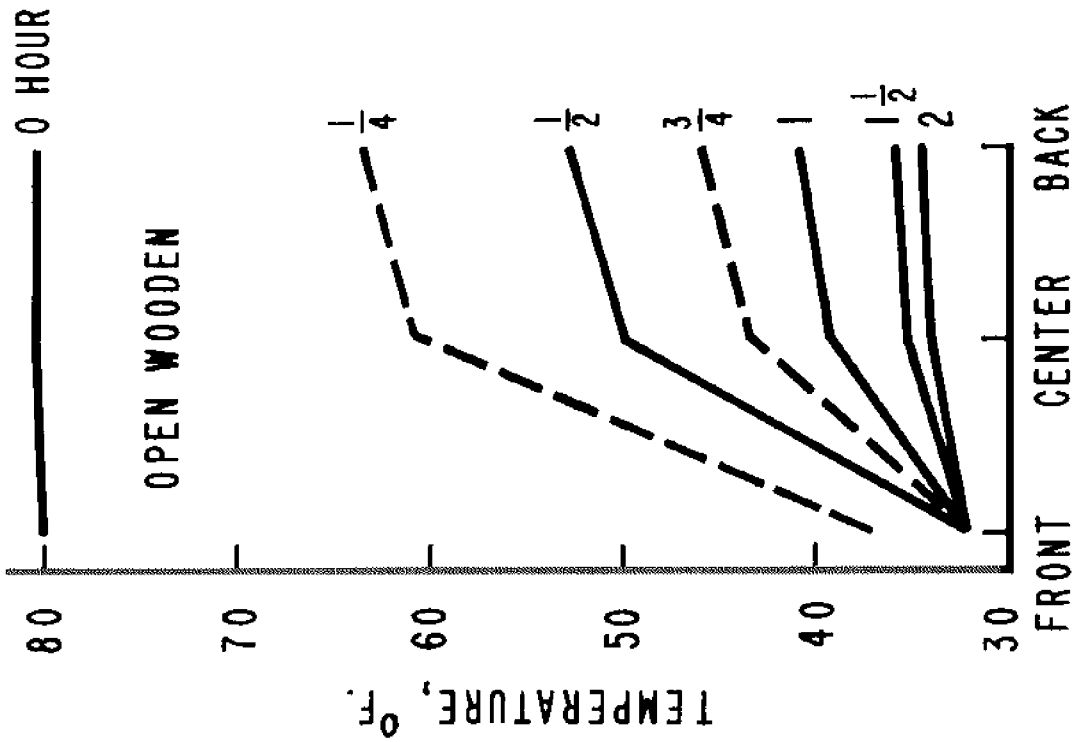

FIG. 48 Temperature gradients parallel to air flow. Open wooden basket cooled with mechanical refrigeration.

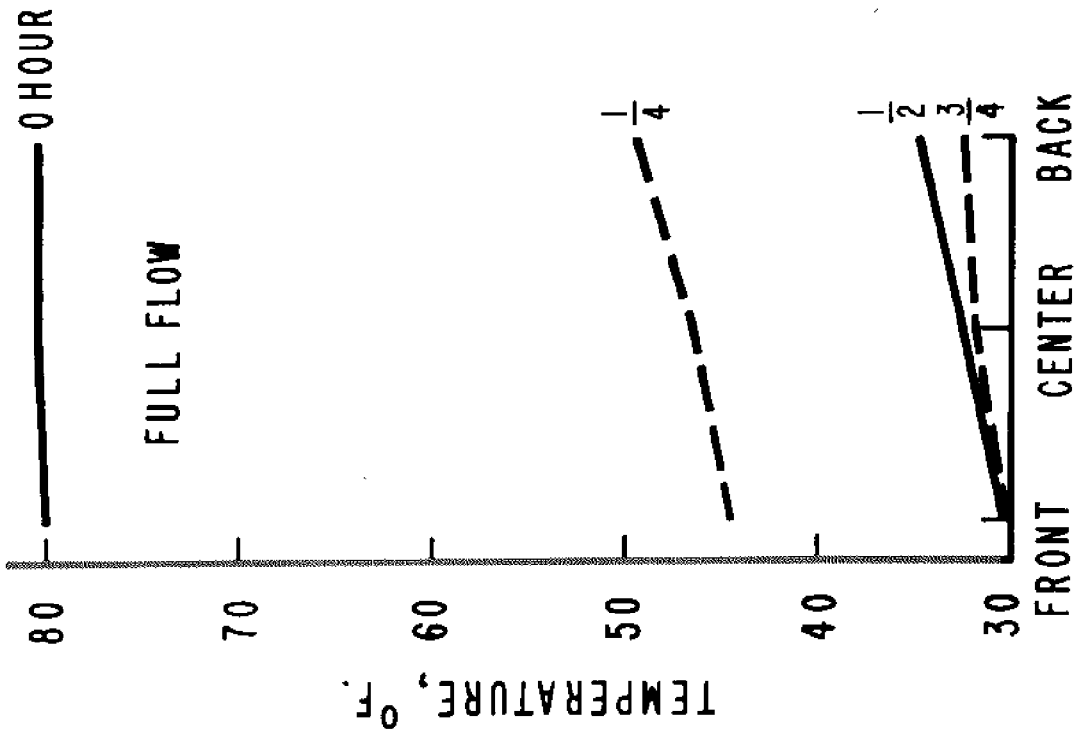

FIG. 49 Temperature gradients parallel to air flow. Full flow container cooled with mechanical refrigeration.

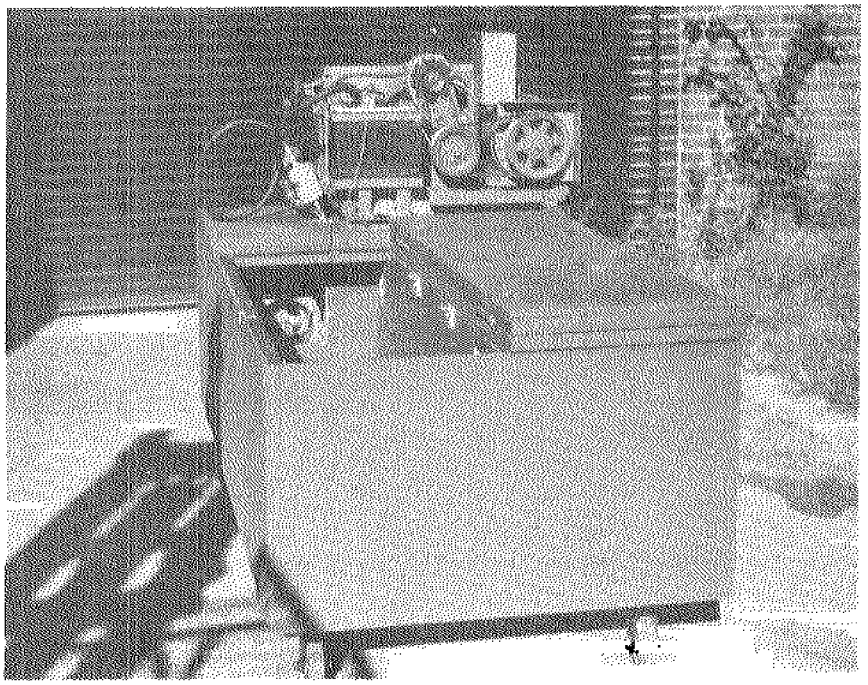

FIG. 50 Six-bushel forced air clam cooling unit as tested with the mechanical refrigeration unit.

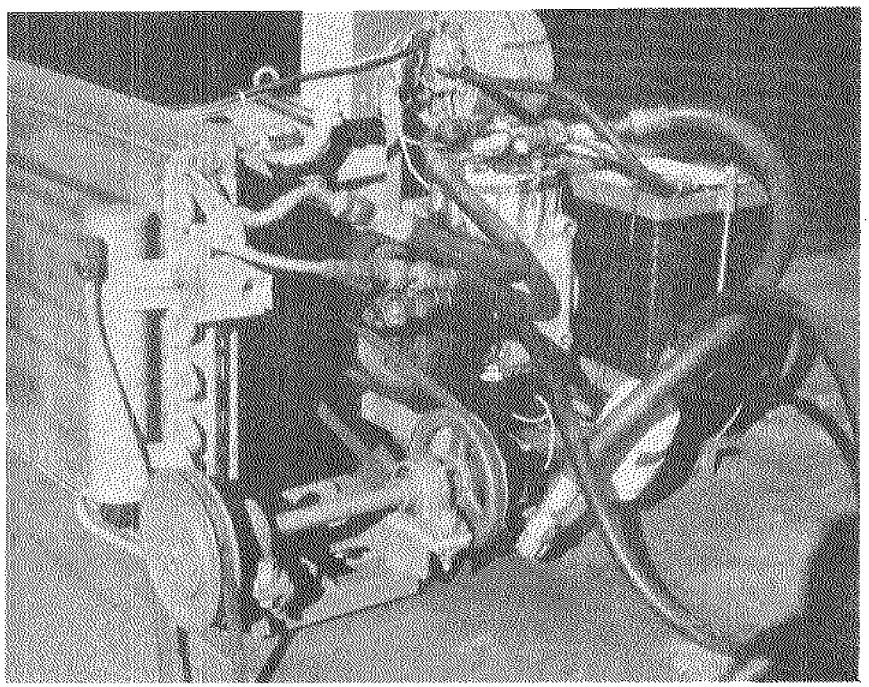

FIG. 51 Jack shaft on the refrigeration unit used to power the blower.

driven from a jack shaft on the refrigeration unit (Fig. 51) or, if ice were the cooling source, by a 3/4 horsepower 3-Phase electric motor. Box construction features included a 1/4 inch plywood inner panel, one inch of styrofoam insulation and an outer 1/2 inch plywood panel. Gaskets on the lid-box interface reduced air leakage.

When air returned through the underfloor plenum, loading was either in one channel for the first three containers followed by loading in the second channel, or loading in alternating channels as each basket was placed in the unit. Manual air baffle manipulation was required to divert all air into the first channel loaded. The first basket placed in the second channel required readjustment of the baffles to divide air flow between the two channels. Directing air flow through the two parallel channels reduced air flow per channel and, consequently, reduced the cooling rate.

Loading sequence was such that the downstream location was utilized first. Therefore each container was exposed to a fresh supply of cold air for 15 minutes, at which time a warm basket was placed upstream from it. With alternate side loading this interval was 30 minutes.

Cooling results using ice in the parallel chamber configuration are presented in Fig. 52 for in-line loading and Fig. 53 for alternate channel loading. Table 19 summarizes the data and indicates that loading sequence made little difference in average temperature of all baskets after 4 1/2 hours of cooling (i.e., 3 hours after the last basket was placed in the box). Comparison of the cooling rates shown in Figs. 52 and 53 also supports this conclusion throughout the cooling period.

"Overhead" heat loss, the ice used only for cooling the box and overcoming heat influx, was found to be 77.5 lbs of ice in 4 1/2 hours when the box was operated in an ambient air temperature of 90^{o}F.

The cooling rate of full flow containers was not tested in the six-bushel unit using ice as the cooling source.

The mechanical refrigeration system was extensively modified for use with the six-bushel cooling unit. The 5 hp drive motor was turned end for end to place it in a position suitable for future replacement with a gasoline engine. Condenser fan support brackets and the drive

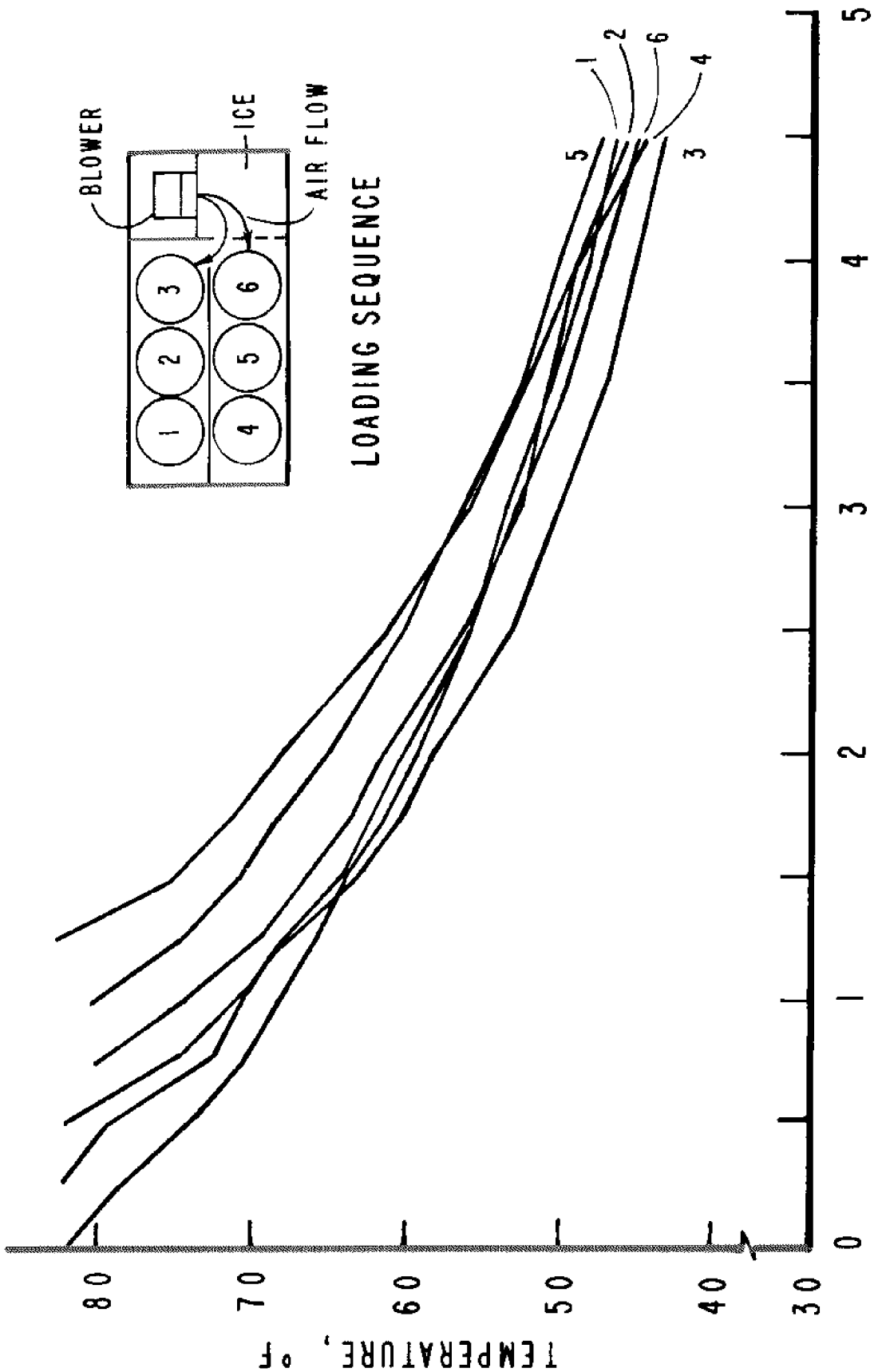

FIG. 52 Cooling rates for six bushels of clams loaded at 15 minute intervals, on-line loadings with ice as the cooling source. Air return through the under floor plenum.

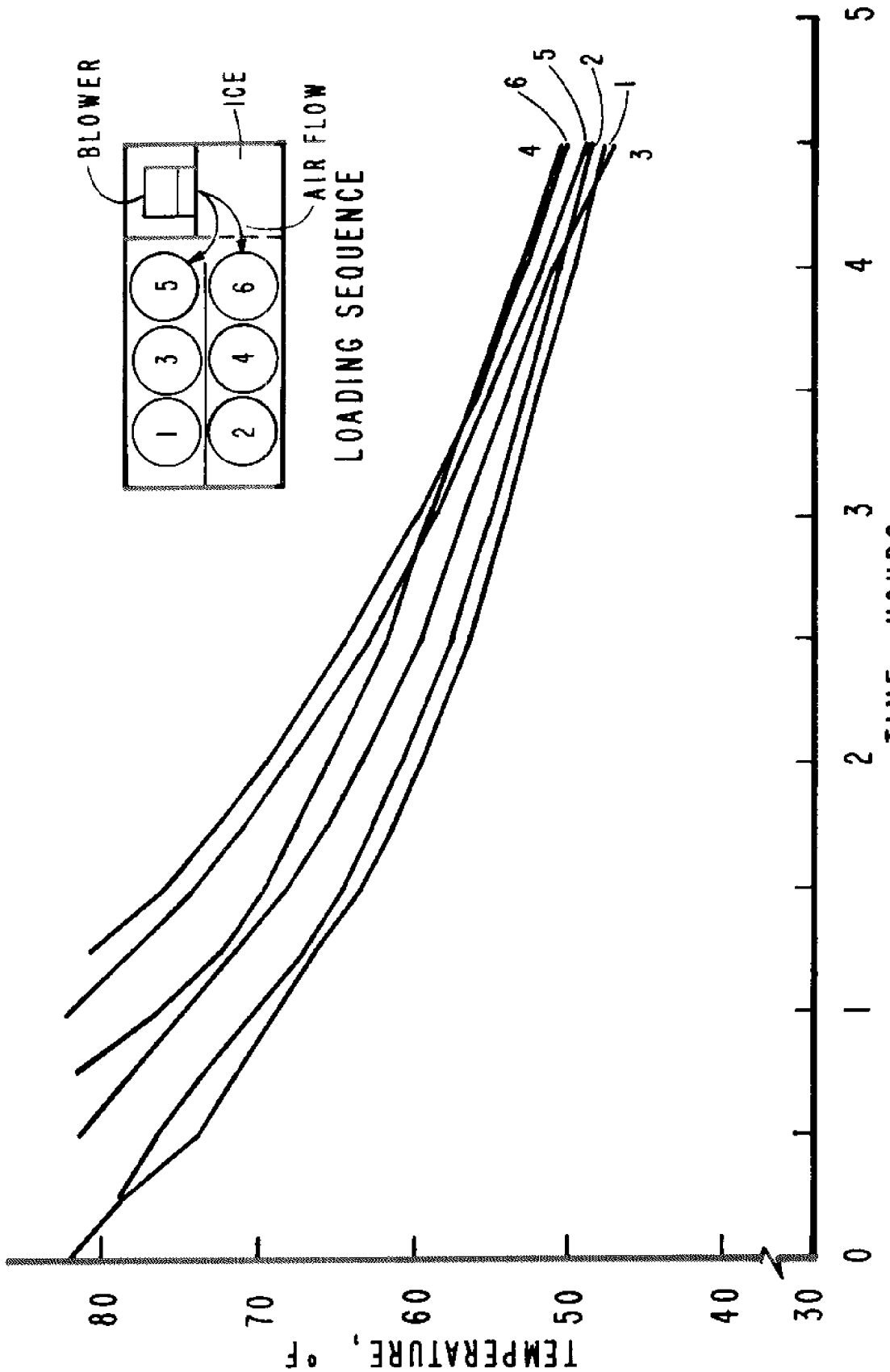

FIG. 53 Cooling rate for six bushels of clams loaded at 15 minute intervals, alternate side loading with ice as the cooling source. Air return through the under floor plenum.

shaft were rebuilt and strengthened. A jack shaft, driven from the condenser fan shaft, was added to supply power to the blower. A high pressure cutout was added to the refrigeration system for safety purposes. Refrigerant pressure gauges for the high and low side were installed to monitor operation. No changes were made to the two parallel evaporators.

TABLE 19. RESULTS OF COOLING 6 BUSHELS OF CLAMS, LOADED AT 15 MINUTE INTERVALS, WITH TWO SEQUENCES OF LOADING

Loading sequence	No. tests	Ice used, lb	Average initial temp, deg F	Average temp at 4 1/2 hr, deg F	Btu per* lb deg F
In-line	2	175.5	81.7	46.0	2.0
Alternate	2	162.8	81.1	48.9	2.2

*Btu of ice used per lb of clams per deg F

Several preliminary tests were conducted with the cooling chambers in parallel, i.e., air return via the underfloor plenum. The problems of baffle position adjustment persisted with test personnel either forgetting to move one at the correct time or guessing at an incorrect setting, the result of which was unequal channel cooling. The unit was modified by blocking off the underfloor plenum, removing a section of the center baffle at the end opposite the blower and opening an inlet hole into the blower compartment adjacent to the blower. Air then flowed in a horizontal U-pattern. The first basket to be loaded was placed next to the blower inlet while the last to be loaded was placed just after the evaporator.

It was observed that baskets cooled unevenly. Some of this was attributed to varied widths between the slats of the individual baskets. Uniformity of slat spacing was achieved by recutting all grooves to 1/2 inch wide with the basket dry. Swelling of the slats when wet reduced the spacing to approximately 3/8 inch.

The presence of ice on the evaporator coil, when not corrected, reduced air volume and the cooling rate. Several solutions to this problem were investigated. One was to shut off the compressor for several minutes until the ice melted. The amount of time needed depended on the severity of icing and the overall temperature within the unit. For a given amount of ice, the defrost time was lengthened the further into the test the icing occurred. Attempts were made to detect evaporator icing electronically by means of a light beam, photo cell, appropriate time delays and a switching circuit to control the compressor clutch. Problems occurred due to the thermal sensitivity of the light detecting transister. The designer of the circuitry felt that a working freeze-up detector could be developed, but time did not permit complete development.

Another means to eliminate evaporator freeze-up was through the use of a hot gas bypass valve installed in the refrigeration system just after the compressor. The valve sensed evaporator pressure which is directly proportional to evaporator temperature. When the pressure dropped below a certain preset point, the valve opened to allow a small amount of hot refrigerant gas to bypass the condenser and expansion valve in order to raise the evaporator pressure. When properly set, the valve served to maintain the temperature of the evaporator just above the point where ice formation occurred.

The performance of the mechanical refrigeration system with respect to cooling six bushels of clams loaded singly at 15 minute intervals is presented. Fig. 54 provides the cooling curves for the modified wooden basket and a blower speed of 900 rpm. Fig. 55 shows the results of cooling the full flow container at a blower speed of 900 rpm. Fig. 56 shows the results of cooling the modified wooden basket at a blower speed of 1100 rpm; Fig. 57 shows the cooling rate for the full flow container at 1100 rpm; and Figs. 58 and 59 show the cooling rate for both container types at 1300 rpm. Table 20 summarizes the data.

The value of ΔT in Table 20 is the difference between the average of the temperatures of the six containers as they were placed in the cooler and the average of all containers at 2 hours from the start of the test.

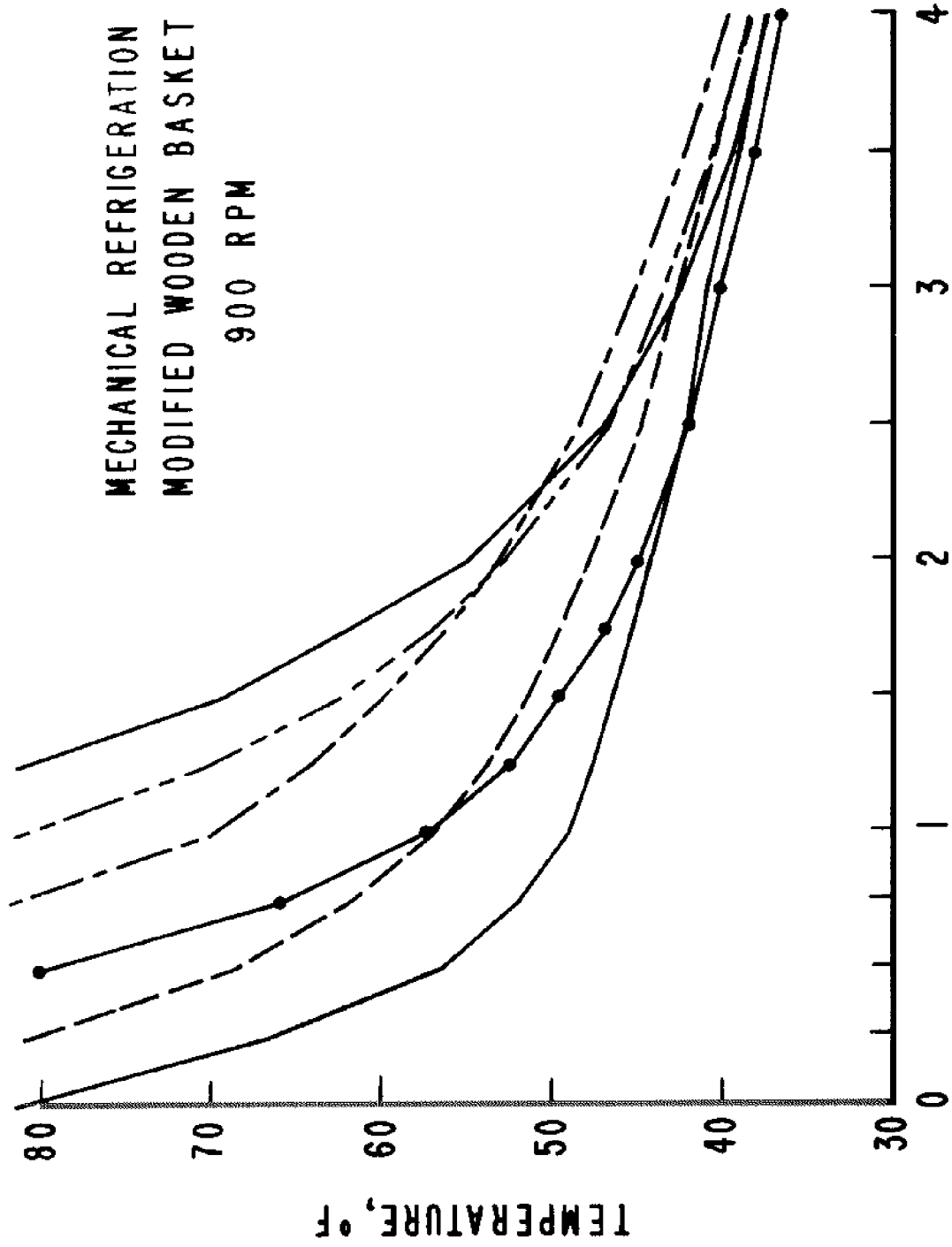

FIG. 54 Cooling rate for six bushels of clams loaded at 15 minute intervals. Mechanical refrigeration, a 900 rpm blower speed and the modified wooden baskets were used.

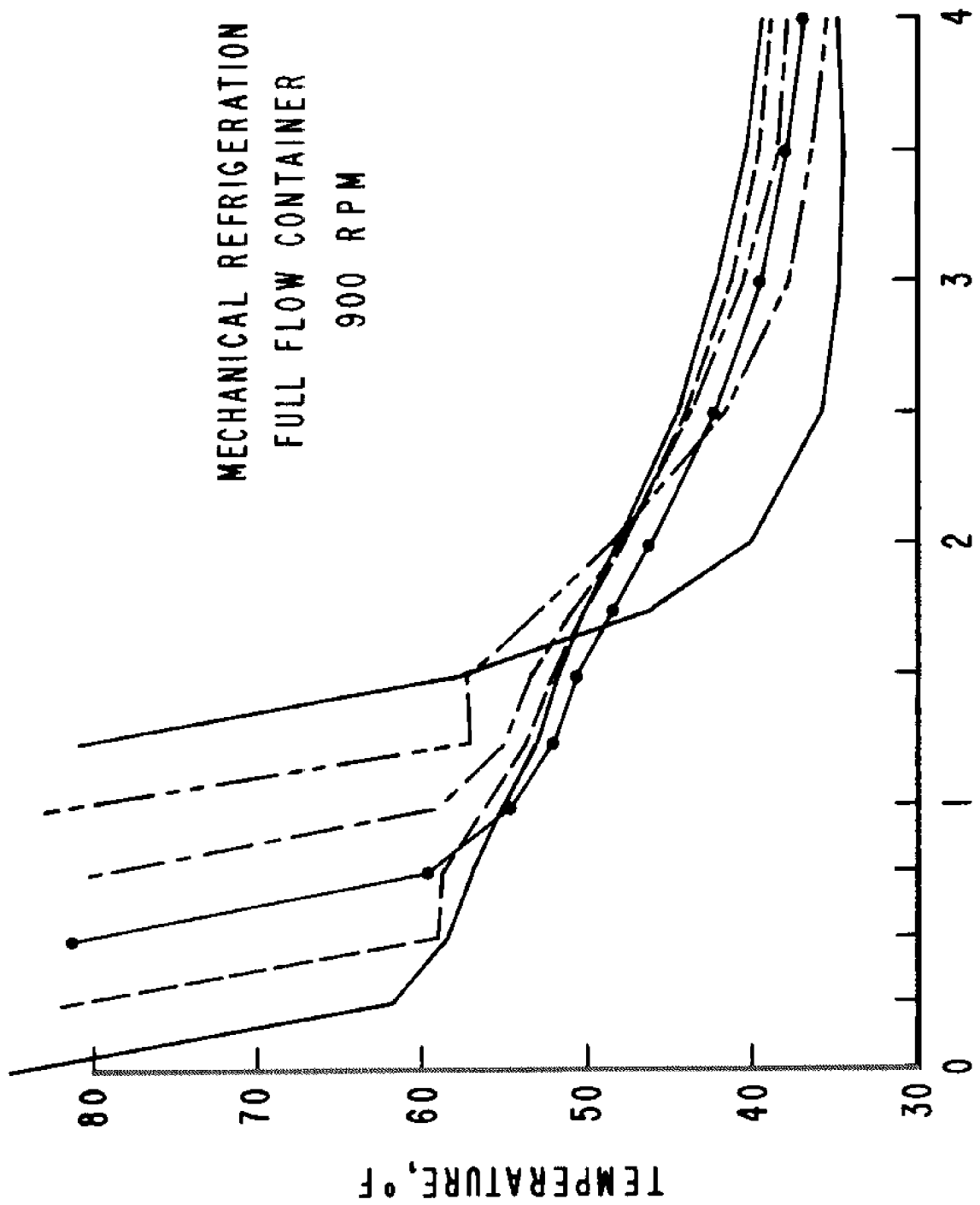

FIG. 55 Cooling rate for six bushels of clams. Mechanical refrigeration, a 900 rpm blower speed and the full flow containers were used.

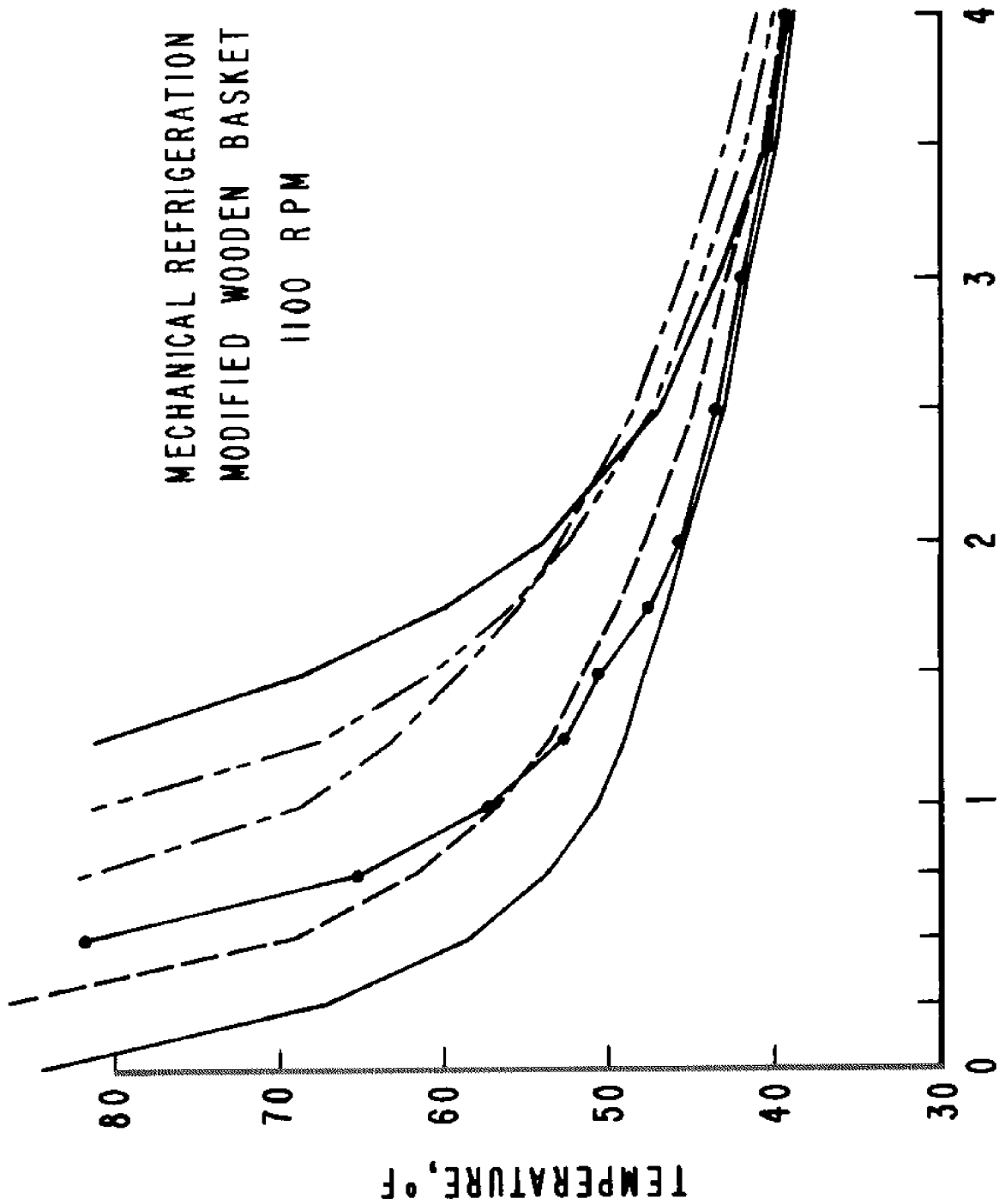

FIG. 56 Cooling rate for six bushels of clams loaded at 15 minute intervals. Mechanical refrigeration, an 1100 rpm blower speed and the modified wooden baskets were used.

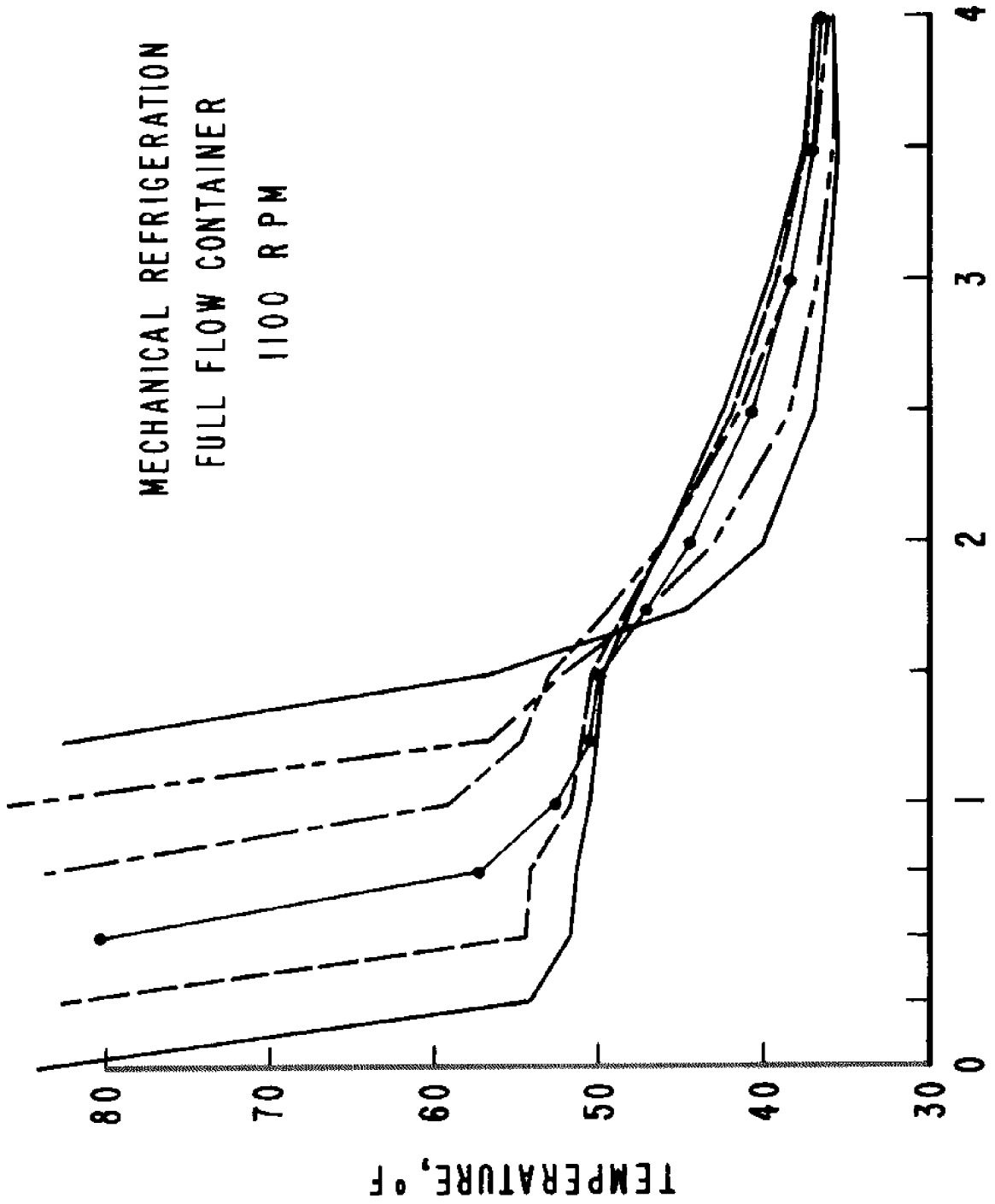

FIG. 57 Cooling rate for six bushels of clams loaded at 15 minute intervals. Mechanical refrigeration, an 1100 rpm blower speed and the full flow containers were used.

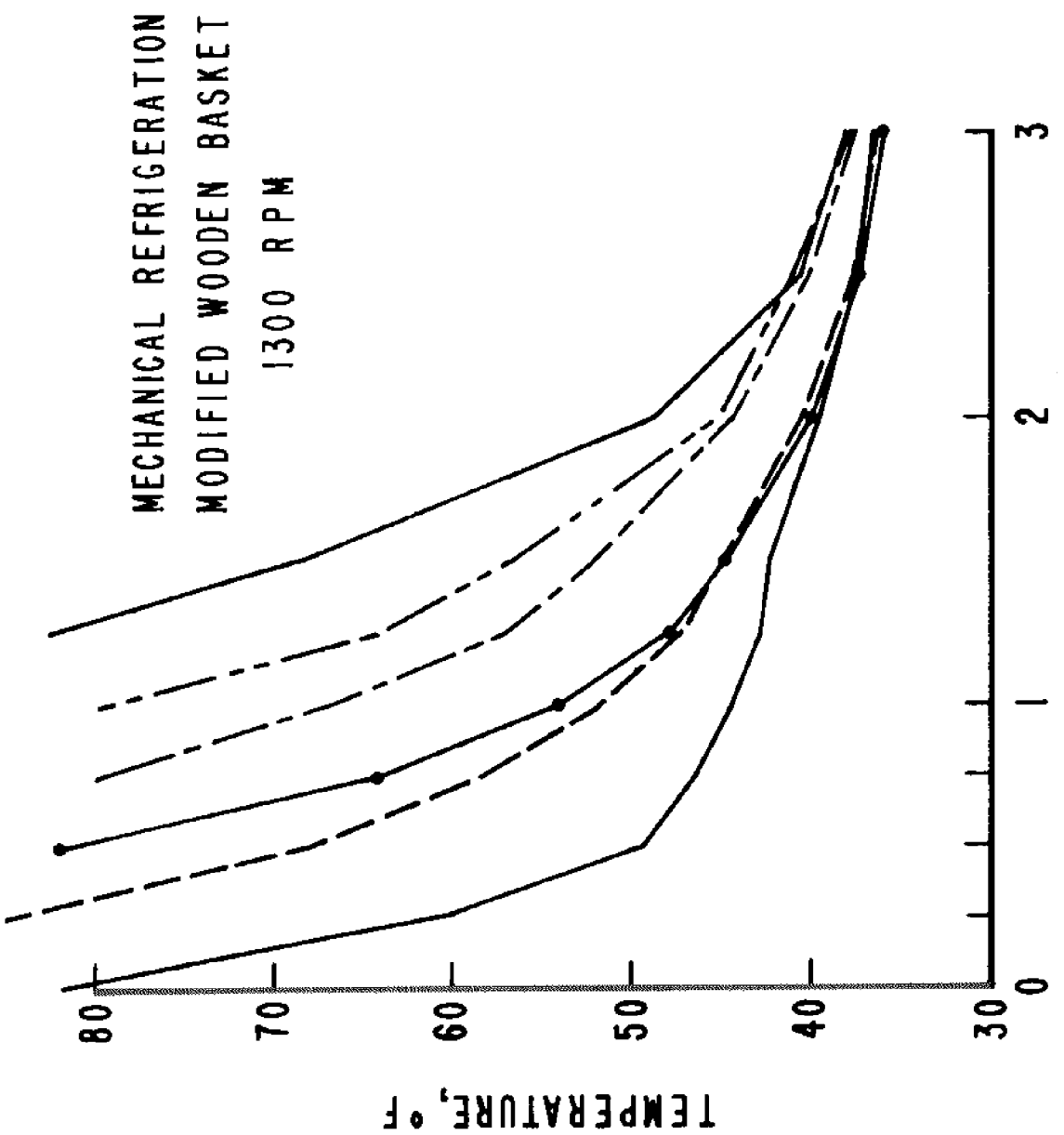

FIG. 58 Cooling rate for six bushels of clams loaded at 15 minute intervals. Mechanical refrigeration, a 1300 rpm blower speed and the modified wooden baskets were used.

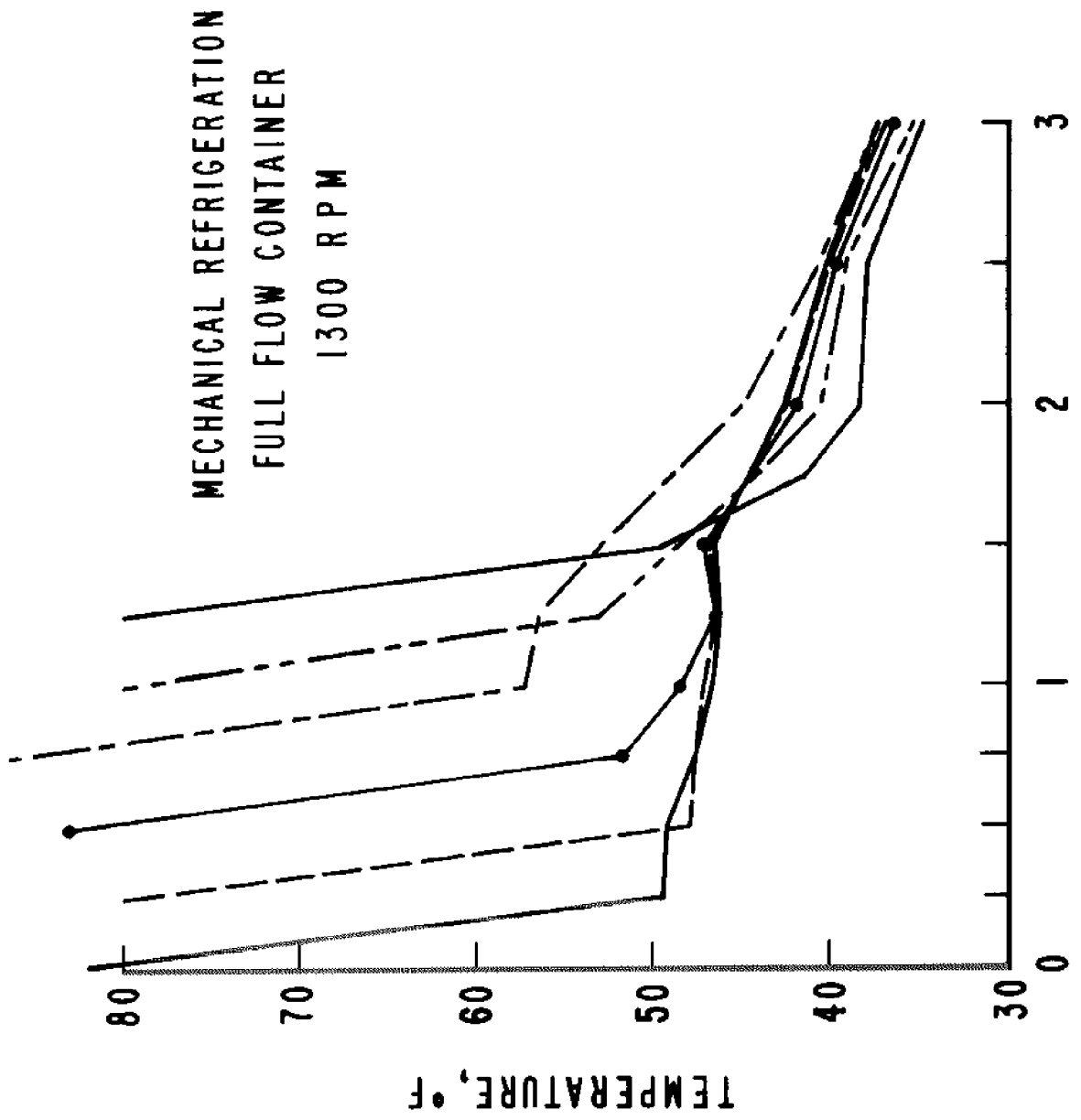

FIG. 59 Cooling rate for six bushels of clams loaded at 15 minute intervals. Mechanical refrigeration, a 1300 rpm blower speed and the full flow containers were used.

Figs. 54-59 and Table 20 point out that the cooling rate is greater for the full flow container than for the modified basket. Also, cooling rate increases as air flow rate, as indicated by a higher blower speed, increases. The amount of cooling effected prior to the addition of another basket was greater at the higher blower speeds. The rate of cooling during the first 15 minute period is greatly reduced upon addition of a warm container upstream from it. Thus, it is important that system capacity and air flow rate be designed to cool each container to the desired temperature prior to the addition of the next harvested container. Since the same refrigeration capacity was available in all tests, these tests demonstrate that providing sufficient refrigeration capacity in terms of compressor size to cool the clams is not sufficient for efficient or even adequate cooling. Sufficient air flow must also be provided to cool the clams. Because of these problems, refrigeration equipment for on-board, or any application, should not be "jury rigged" but must be designed by a competent refrigeration specialist.

TABLE 20. SUMMARY OF SIX-BUSHEL MECHANICAL REFRIGERATION DATA

Blower speed, rpm	No. tests	Container*	Δ T at 2 hrs, deg F	Temperature at 4 hrs, deg F	Figure reference
900	2	MWB	31.5	37.8	54
900	2	FFC	35.6	37.3**	55
1100	2	MWB	33.2	39.6	56
1100	2	FFC	38.9	36.4	57
1300	1	MWB	38.8	37.1 (3 hrs)	58
1300	1	FFC	40.2	36.3 (3 hrs)	59

*MWB - Modified wooden basket
FFC - Full flow container

**One of the two tests was conducted with the hot gas bypass valve installed.

The refrigeration system capacity was estimated based on measurements of blower speed, static blower pressure and the difference in air temperatures across the evaporator. From the above values of pressure and rpm and the performance tables for the blower, an air flow volume was calculated. The only measurements needed to use the blower tables were static pressure and blower rpm. The latter is easily and accurately determined. A 25% error in measuring the pressure would result in a 9% error in calculated blower capacity (this figured at 900 rpm and 0.2 in. water). Refrigeration capacity was calculated using an air density of 0.081 lbm per cu. ft. and a specific heat of air of 0.24 Btu per lbm-^{o}F (at 32^{o}F). Table 21 provides a summary of the calculated values.

TABLE 21. ESTIMATE OF HEAT CAPACITY OF REFRIGERATION SYSTEM

Test No.	Container*	Blower speed, rpm	Static pressure, in. H_2O	Air Vol, cfm	Δ T, F deg	Capacity, Btu/hr
6B-22	FFC	900	.2	764	20.6	18,360
6B-26	MWB	1100	.3	926	6.9	7,450
6B-29	FFC	1300	.37	1150	10.6	14,220

*FFC = Full flow container
MWB = Modified wooden basket

The temperature drop across the evaporator, ΔT, was the average of the three highest instantaneous differences as measured at the 15 minute recorder cycling intervals. Tests 6B-26 and 6B-29 were conducted with the hot gas bypass valve installed, and it is apparent that system capacity is reduced due to the short circuiting of refrigerant. In addition, it was determined that the average air temperature reaching the first container was 34.6^{o}F without the valve and 40.7^{o}F with the valve. Insufficient tests were conducted with the bypass valve installed to fully measure its effect on system capacity and cooling ability.

The six-bushel cooling unit was made portable through the direct replacement of the electric motor with a gasoline engine (Fig. 60). A centrifugal clutch was attached to the engine crank shaft to remove the load at starting. The motor had sufficient power to run the unit, even at partial throttle. Vibration of the entire unit was severe. The engine was attached through rubber mounting blocks, but this did not provide sufficient vibration damping. Fear of refrigeration tubing failure (a safety hazard) due to the vibration dictated that the unit not be tested. Time did not permit remounting of the engine.

Conclusions

Soft shell clams can be rapidly and effectively cooled in the container into which they were placed at harvest. The rate of cooling was found to be directly proportional to the amount of cooling air forced through the container. In turn, the amount of air passing through the container depended, in order of importance, on the openness of the container side, the air flow rate applied and the shape of the container as it affected air bypass around the container. With no forced air flow as in a natural convection unit, container design had no effect on the cooling rate, but cooling was slow.

The source of cooling also affected cooling rate in the several units tested. Dry ice caused more rapid cooling than ice in the natural convection unit and in the one-bushel forced air unit. Mechanical refrigeration provided more rapid cooling than ice in the two forced air units due to its increased cooling potential and lower restriction of air flow. Using dry ice presents some risk of freezing the clams due to the low temperature of dry ice.

Cooling without forced air resulted in an estimated cooling time from 80°F to 50°F of 7 to 8 hours and to 40°F of 10 to 12 hours. With forced air and ice, cooling to 50°F was accomplished in 4.4 hours with a closed side wooden basket, in 2.0 hours with a 12% open side basket and in 0.6 hours for the full flow container. A single full flow container of clams was cooled to 50°F in 0.25 hour using mechanical refrigeration. In a six-bushel unit with mechanical refrigeration,

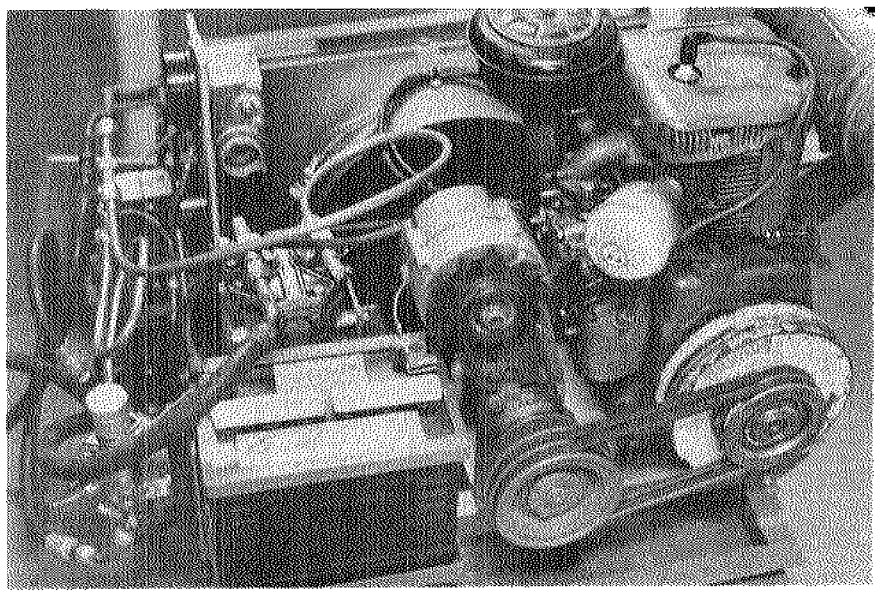

FIG. 60 Gasoline engine installed on the mechanical refrigeration system making it portable.

clams placed into the unit at 15 minute intervals were cooled an average of 30 F degrees within 15 minutes of the time of loading.

Of the cooling methods tested, the system using natural air convection and ice or dry ice appeared to be least useful to the industry due to its slow cooling rate. The use of dry ice as a cooling source was felt to be impractical due to its general unavailability, high cost and specific handling requirements. The use of ice for on-board cooling would be a workable method for the waterman who can manufacture his own or otherwise readily obtain it.

A refrigeration system could be installed on some but not all clam boats. Three sources of power are suitable for supplying the power to run a refrigeration system on a clam boat: the boat's push motor, the pump motor or an auxilliary internal combustion engine. Drawbacks exist for all three. The push motor is operated at a normal speed during travel to and from the harvest area but at slow speed during dredging. The pump motor operates only during the dredging operation. A third internal combustion engine adds to initial costs, operational costs and noise during operation. Transfer of power from the power source to the compressor can be mechanical (i.e., a V-belt drive), hydraulic or electrical (by use of a generator-motor combination). The main advantage of electrical power transmission is in the use of the hermetically sealed compressor (compressor and motor are sealed within the refrigeration system). Items of expense would include boat modification, the cooling box, a refrigeration system and a source of power. The maintenance required by the refrigeration and cooling system would be a significant addition to that already required by the boat and harvest equipment.

V. ON-BOARD COOLING OF SOFT CLAM SHELLSTOCK

The studies of the growth rate of bacteria in clam shellstock determined that a correlation existed between temperature, time and bacteria numbers. A storage temperature of 70°F or above allowed a greater rate of bacterial growth than did a temperature of 50°F or lower. Clam temperatures of 80°F have been observed as they were taken from the water. It is the industry practice to temporarily store harvested baskets on the boat deck and/or truck until refrigerated. Clam temperatures of 85°F in the center of the basket have been observed during this period. These naturally occurring temperatures are well within the range previously found to contribute to rapid bacterial growth in the clams. It was, therefore, suggested that cooling immediately upon harvest might improve bacterial quality of the clams when compared to clams allowed to remain warm for longer periods of time after harvest. Thus, two studies were undertaken to establish the effect of immediate cooling on clam quality: a limited study in 1974 and a more extensive study in 1975.

The 1974 Tests

Procedure

The 1974 study was designed to answer the following two questions: 1. What is the effect of immediate cooling of clams after harvest on the bacteria level at one hour after harvest? This was prompted by a finding that the bacteria level of highly contaminated clams rapidly increased within the first 1/2 hour after harvest (personal communication with Mr. William King, Maryland Department of Health & Mental Hygiene). And question 2: Because of this possibility of rapid bacteria growth, must the bacterial analysis procedure be initiated on the boat through the use of a portable lab, or will the results be similar if live clam samples are iced and transported to a laboratory for analysis as is the current standard procedure.

Five harvesting trips on the clam dredge Tiny Lou were made for this study. The necessary equipment included the one-bushel forced air cooling unit described in section IV, a 1500 watt engine driven generator to operate the blower motor, two conventional wooden bushel baskets and a shop constructed full flow container. Sufficient laboratory equipment was taken on board to initiate bacteria analysis, some of which is shown in Fig. 61. Correct incubation temperature was achieved through the construction of the portable incubator shown in Fig. 62. It consisted of an insulated plywood box heated by three 40 watt light bulbs and a small circulating fan. Temperature was thermostatically controlled. Power for the blenders and incubator was furnished by a small 110V generator already on the boat.

The first trip out served to check out equipment and techniques. Data was collected on the four succeeding trips. Clams were first harvested into the wooden basket and placed on the deck as the control. An empty basket was inverted over the full basket as per current industry requirements. The full flow container was filled with clams as harvested and placed in the cooling unit where it was cooled with ice as the cooling source. The temperature of the clams was reduced to the 40^{o}-$45^{o}F$ range in approximately 35 minutes.

Sampling was done just as filling of the container was completed and again one hour later. The time interval between the filling of the first and second containers provided a one-half hour interval for sample analysis, during which time two samples could be processed. From each container at each sample time, four samples of 8-12 clams each were taken. Two of the samples, in polyethylene bags, were placed in ice for subsequent laboratory analysis. The remaining two were shucked, blended, diluted into appropriate media and placed in the incubator.

Results of 1974 Tests

Results at the two analysis locations (boat vs. lab) were first tabulated, Table 22. A different number of paired samples resulted from a breakdown of the analysis procedure for one or both individuals of several of the sample pairs. Five total coliform values (three from

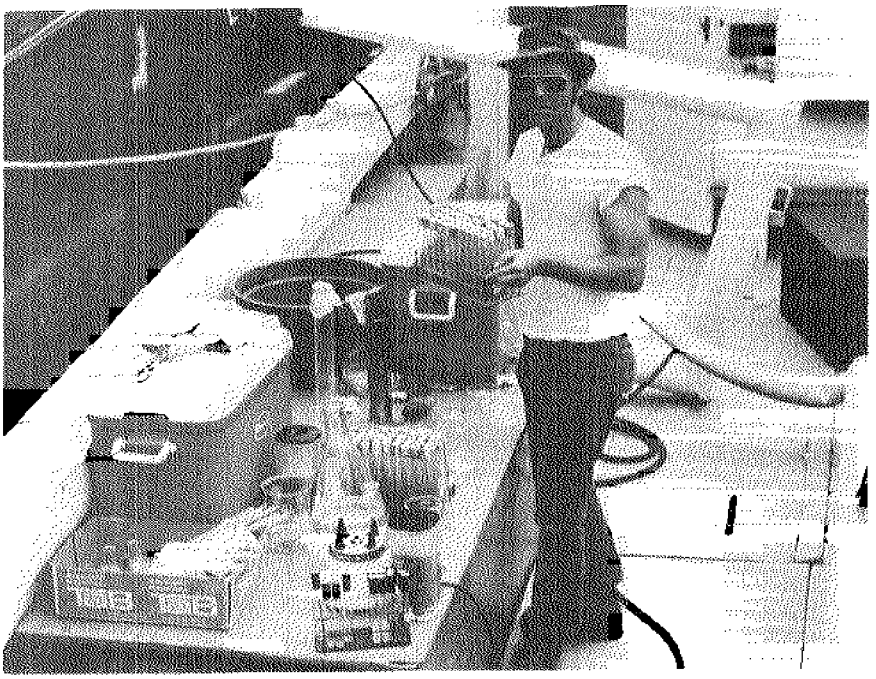

FIG. 61 On-board bacterial analysis equipment.

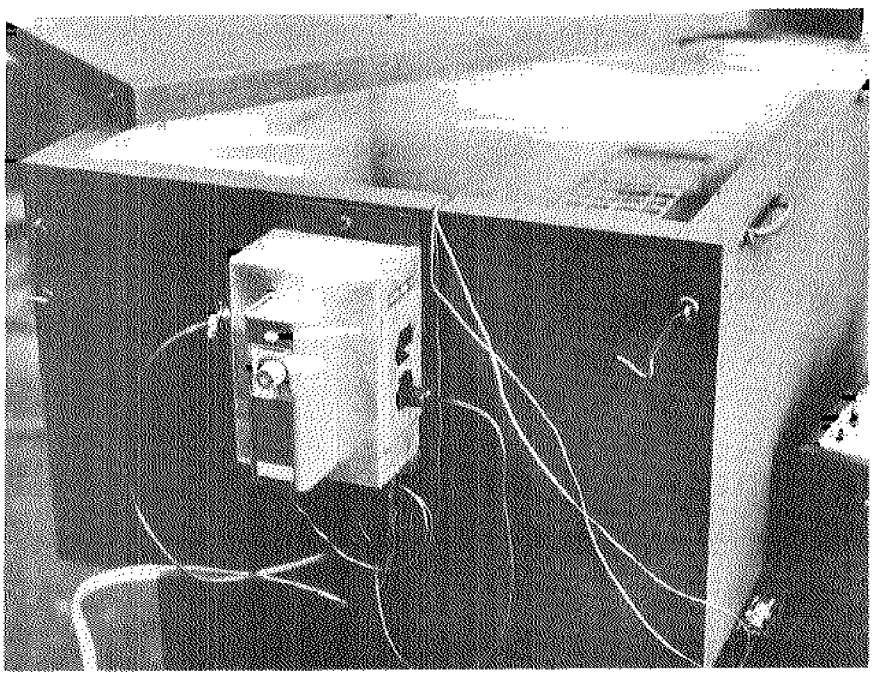

FIG. 62 Portable incubator for on-board bacterial analysis.

boat, two from lab) were above 160,000 per 100 g and were eliminated due to suspected sample contamination.

TABLE 22. COMPARISON OF BACTERIAL ANALYSIS RESULTS WHEN CLAMS WERE PROCESSED ON THE BOAT VS. ICED AND LATER PROCESSED IN THE LABORATORY (1974).

	Plate Count (Count/g)		Total Coliform (count/100g)		Fecal Coliform (count/100g)	
	Boat	Lab	Boat	Lab	Boat	Lab
	151,500	133,000	7,050	1,300	665	250
	148,000	93,000	3,000	1,700	10	2,100
	207,000	125,500	3,150	1,700	20	1,700
	56,000	150,000	17,500	4,420	10	480
	93,500	174,500	11,000	2,950	1,490	70
	157,500	89,000	360	870	680	50
			3,300	13,350	0	0
			2,920	3,550	0	0
			1,400	660	0	0
			3,000	340	0	0
			11,000	29,500	0	105
					85	0
Average	135,600	127,500	5,790	5,485	247	396

Using a paired sample technique the standard error of estimate of the difference was calculated using the logarithm to the base 10 of the plate count, total coliform and fecal coliform data shown in Table 22. The standard error of estimate for the difference in plate count between boat and lab analysis was .043, 1.30 for the total coliform differences and -0.69 for the difference in fecal coliform. None of these values are significantly different at the 5 percent level. Thus, based on the limited tests run there was no difference between starting the laboratory procedure immediately on board the boat or icing the samples and analyzing them after returning to the laboratory. Since icing the samples was much easier and convenient and is the procedure recommended by standard methods, the icing technique was employed for later tests.

The data shown in Table 23 was developed to determine the bacterial growth rate during the first one hour after harvest in clams receiving immediate refrigeration versus clams receiving conventional treatment. Table 23 shows the plate count, total coliform count and fecal coliform count found in soft clams at harvest and when sampled one hour after harvest. The samples designated "cool" were refrigerated on board immediately upon harvest while the samples labeled "warm" were left on the boat deck as is conventionally done in the industry.

TABLE 23. BACTERIAL COUNT IN SOFT-SHELL CLAMS AT HARVEST AND AT ONE HOUR AFTER HARVEST USING CONVENTIONAL PRACTICES AND USING IMMEDIATE ON-BOARD COOLING (ALL VALUES ARE PER GRAM OF SAMPLE)

Plate Count			Total Coliform			Fecal Coliform		
Harvest	Cool	Warm	Harvest	Cool	Warm	Harvest	Cool	Warm
123,000	123,000	114,000	92	26	32	9.3	0	0.2
180,000	173,000	300,000	49	13	28	4.0	0.2	0.2
149,000	82,000	130,000	21	2400	17	4.5	24	17
117,000	104,000	121,000	4.9	1600	17	0.4	18	17
33,000	84,000	127,000	24	130	-	0	27	6.8
80,000	103,000	188,000	39	220	110	0.2	2.7	6.8
88,000	110,000	118,000	17	9.3	35	5.5	0.7	0.4
212,000	239,000	60,000	17	79	24	4.0	0.7	0.6
10,000	3,800	-	4	17	49			
13,000	-	83,000	3.2	49	9.3			
16,000	104,000	85,000	2.4	47	49			
18,000	13,000	19,000	15	220	22			
5,400	12,300	14,600	14	49	110			
			2.1	3.4	240			
			11	3.4	350			

The data in Table 23 was used to determine if there was a rapid bacterial growth in samples within the first one hour after storage. The data was analyzed by first taking the logarithms of all values in Table 23. Then for each set (i.e., plate count, total coliform and fecal coliform data) the differences in the logarithms of paired

samples were calculated. Differences calculated were the "cool" samples minus the as harvested values, "warm" samples minus the as harvested values and the "warm" values minus the "cool" values. Standard error of estimate was calculated for each difference and its statistical significance calculated by means of a t test.

Table 24 shows the mean of the differences, the standard deviation of the differences, the number of paired samples and the standard error of estimate for each difference calculated. The plate count data show that the nonrefrigerated, "warm," samples had a statistically detectable increase in bacterial numbers after one hour. A change in bacterial population in the cooled samples was not detectable within the one hour test period. Plate count data also show there were no statistically significant differences in the difference in bacteria numbers between "cool" and "warm" samples after one hour. Thus, for plate count there was a detectable bacterial growth in only the nonrefrigerated baskets in one hour, but at the end of one hour there was no detectable difference between the "warm" and "cool" samples. This apparent contradiction can be explained if the "cool" samples experienced some bacterial growth during the first hour, but the difference between at harvest and one hour later was insufficient to be statistically detectable. However, this growth was sufficient to eliminate a statistically significant difference between the "cool" and "warm" samples after one hour.

Total coliform data, Table 24, indicates there was a statistically significant increase in total coliform populations in both the "cool" and "warm" samples during the one hour test period. Since there was no detectable difference between "warm" and "cool" samples after one hour, total coliform growth under the two treatments appeared to be nearly the same during the test period.

Fecal coliform growth was insufficient during the one hour test period to be detected. Thus, fecal coliform growth rate cannot be determined in a one hour period for the clams used and the limited number of samples available. It should be noted that there were no fecal coliforms detected in many of the samples tested at any time. Thus, since these samples gave no information on fecal coliform growth,

it resulted in a smaller number of samples available for fecal coliform comparisons.

TABLE 24. ANALYSIS OF DIFFERENCES IN BACTERIAL COUNT FOR SOFT CLAMS AT HARVEST AND ONE HOUR LATER (BASED ON LOGARITHM TO THE BASE 10 OF THE ACTUAL COUNTS)

Difference	Number of paired samples	Mean difference	Standard deviation of difference	Sample T value
		Plate Count		
Cool-Harvest	12	.08	.33	0.84
Warm-Harvest	12	.22	.38	2.01*
Warm-Cool	11	.045	.24	0.62
		Total Coliform		
Cool-Harvest	15	.66	.92	2.78*
Warm-Harvest	14	.58	.71	3.06*
Warm-Cool	14	.08	1.19	0.24
		Fecal Coliform		
Cool-Harvest	8	.13	1.22	0.30
Warm-Harvest	8	-.05	1.34	-0.11
Warm-Cool	8	-.18	0.35	-1.45

*Significantly different from zero at the 5.0 percent level.

The 1975 Tests

Procedure

The lack of short term effects of immediate cooling did not rule out a possible effect over a longer period of time. The 1975 on-board cooling studies were designed to compare the current industry handling practices against the use of immediate cooling after harvest when compared over a 48 to 50 hour period. Industry methods were the control and included the placement of full baskets on the boat deck

with an inverted basket over the top of each providing the only environmental control. Upon docking, the full baskets were transported by truck to a walk-in cooler. In the industry the time interval from harvest to cooler may be as long as 9 hours for first harvested baskets but will be less than six hours for the average basket harvested.

A boat and clam dredge "Tammy Lynn", Fig. 63, operating out of Shadyside, Maryland, was provided on a contract basis for this study. Testing was started in May to correspond to the onset of warmer weather and water and continued on a weekly basis up to mid-September. A maximum of one test per week was possible since sampling and analysis required six days.

The tests were organized to include a control and treatment in each of two groups. The control clams were harvested in new conventional wooden bushel baskets, covered with an inverted basket and placed on the boat deck at ambient temperature. The treated clams were harvested into shop constructed full flow containers. The full flow containers were cooled immediately upon filling on the harvest boat and maintained at 40°F until placed in a refrigerated storage box. Two different refrigerated boxes were used, with one treatment and one control basket going to each. The first was a borrowed reshipper's cooler adjacent to the boat dock. This consisted of a reclaimed refrigerated truck body of sufficient size to allow baskets to be placed five wide, five high and eight deep front to back. However, test baskets were placed near the door to provide accessibility for sampling and to avoid mixup with commercial clams. The second refrigeration system was a household refrigerator in the Agricultural Engineering Department in College Park. This was modified slightly to use a more accurate thermostat. Thermocouple wires were placed in three clams near the center of the control basket to monitor temperature pull down rate. The full flow container was monitored for temperature stability as was the refrigerator air temperature.

A flow chart for the four containers is provided in Fig. 64. Containers were harvested in numerical order as fast as resource availability would permit. This was as little as 20 minutes, but more often 60 minutes or more per bushel. Container number 1 (control) and

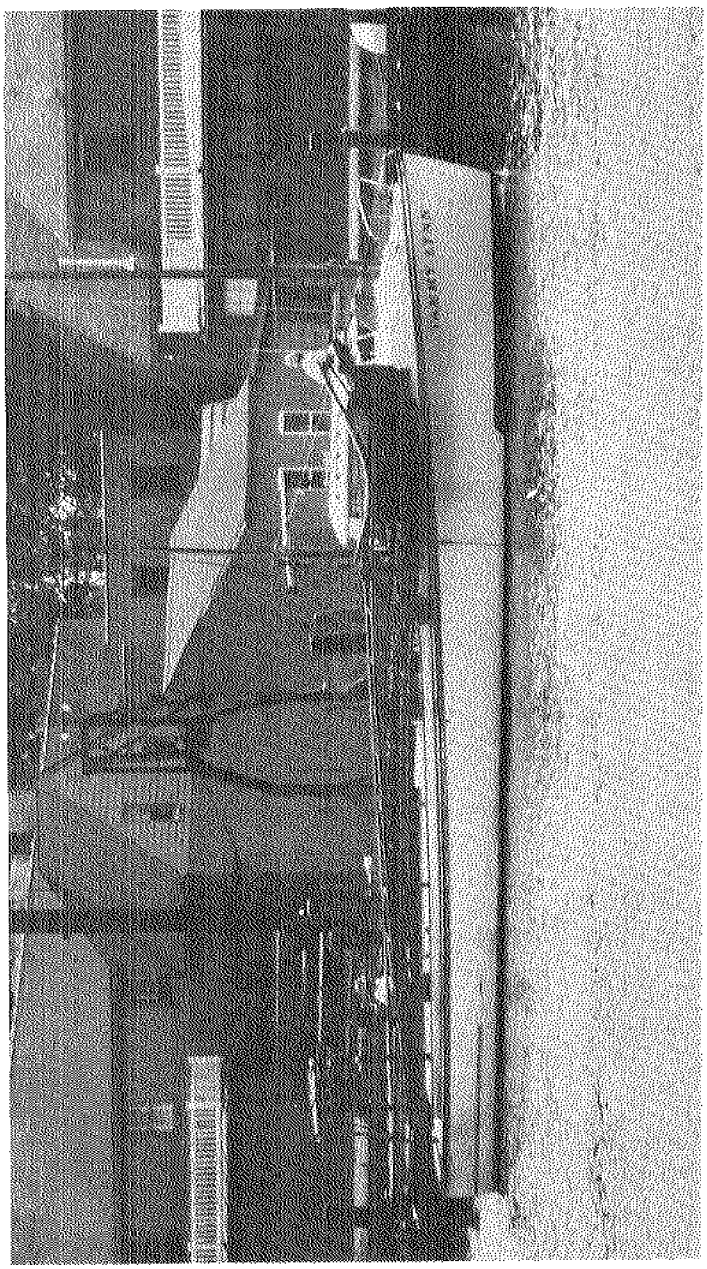

FIG. 63 Clam boat used for the 1975 on-board cooling studies.

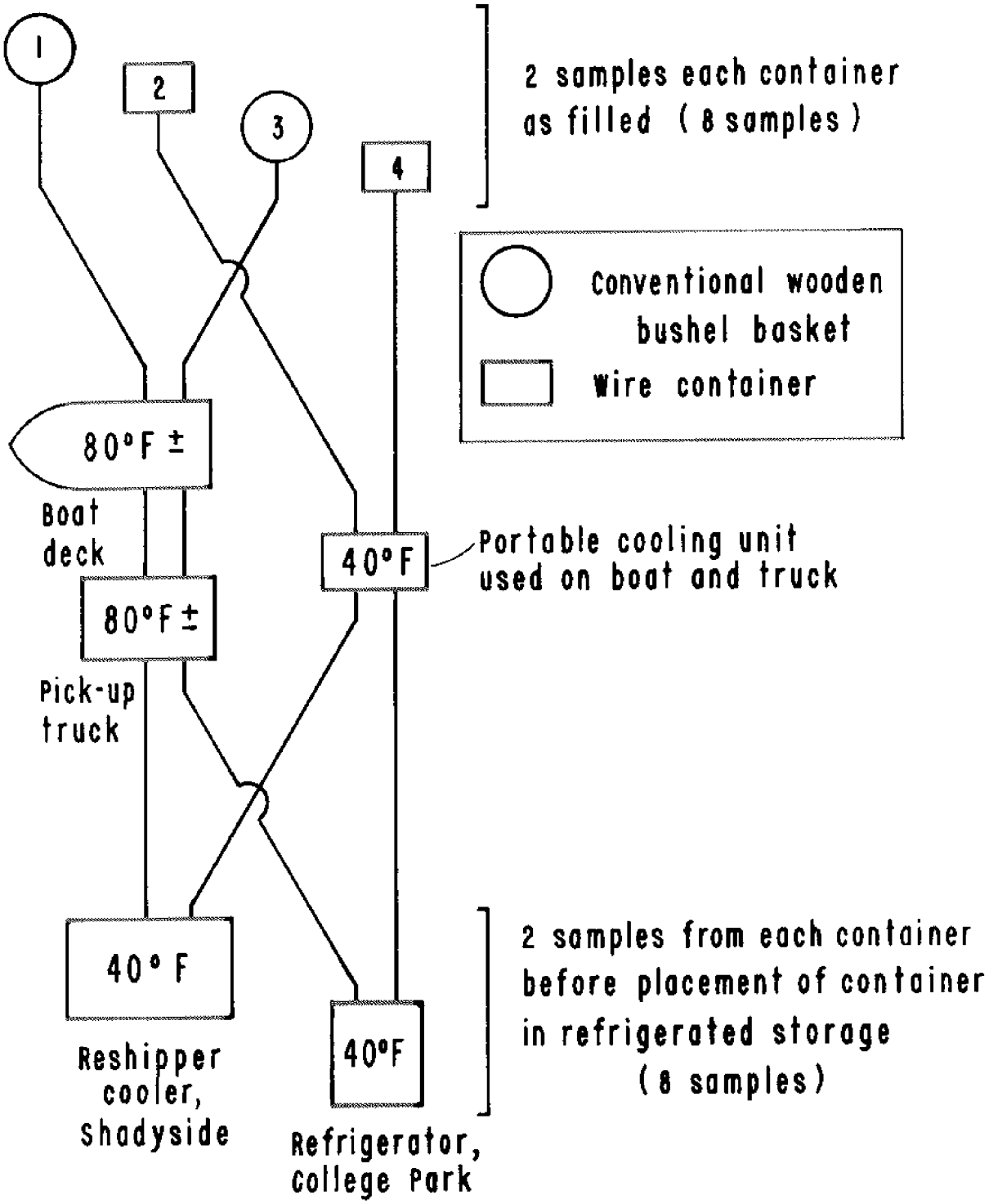

FIG. 64 Flow chart and sample schedule for the 1975 on-board cooling studies.

number 2 (treatment) went to the reshipper's cooler. Containers number 3 (control) and number 4 (treatment) went to the College Park refrigerator. During transport the treatment containers were kept in the cooling unit and the unit run as necessary to maintain temperature. The 1500 watt portable generator powered the cooling unit blower motor during transport by either boat or truck. The one-bushel cooling unit previously described was used. The ice compartment was shortened slightly to allow room for two of the wire full flow containers. The containers in turn were built to hold slightly less than one bushel so that both would fit into the cooling channel.

The number of clam samples taken during each week's study was limited by the capacity of the laboratory to 32. Two samples were taken from each container at four separate sample times. Samples were taken as soon as the container was filled, just prior to placing it in the storage refrigerator, at approximately 25 hours after harvest and at approximately 49 hours after harvest.

The test procedure was as follows. On Friday afternoon four 12 gallon ice chests were filled with ice and placed in a walk-in freezer (ice was not available early Monday morning). The pickup truck was also loaded, Fig. 65, and an additional car acquired. The loading of the cooling unit and generator by one man was made possible by a hoist constructed for this purpose, Fig. 66. On Monday morning the ice was retrieved, loading completed and both truck and car driven to dockside by first light. Travel time from dock to the harvest site varied from 30 minutes to 1 1/4 hours. At the completion of filling of the four containers the boat returned to the dock to unload. The hoist was necessary during unloading as the cooling unit was kept closed during handling with two containers of clams and ice inside. As of docking, the eight harvest samples had been taken and iced. The technician driving the car returned to College Park with these samples and helped a second technician with the initial processing. The pickup truck with one individual remained at the dock to establish the appropriate interval between harvesting and placement into permanent refrigeration. Ambient and basket temperatures were monitored during this period and the containers in the cooling unit were maintained as close to 40°F as possible. At approximately 2:30 PM containers 1 and 2

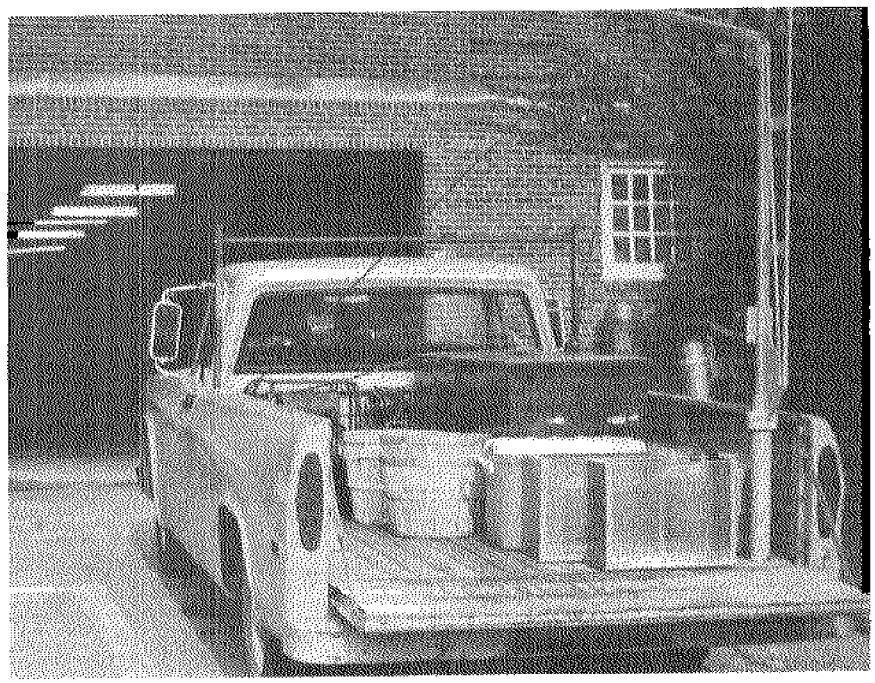

FIG. 65 Pickup truck and equipment used for the 1975 on-board tests. Three additional ice chests are not shown.

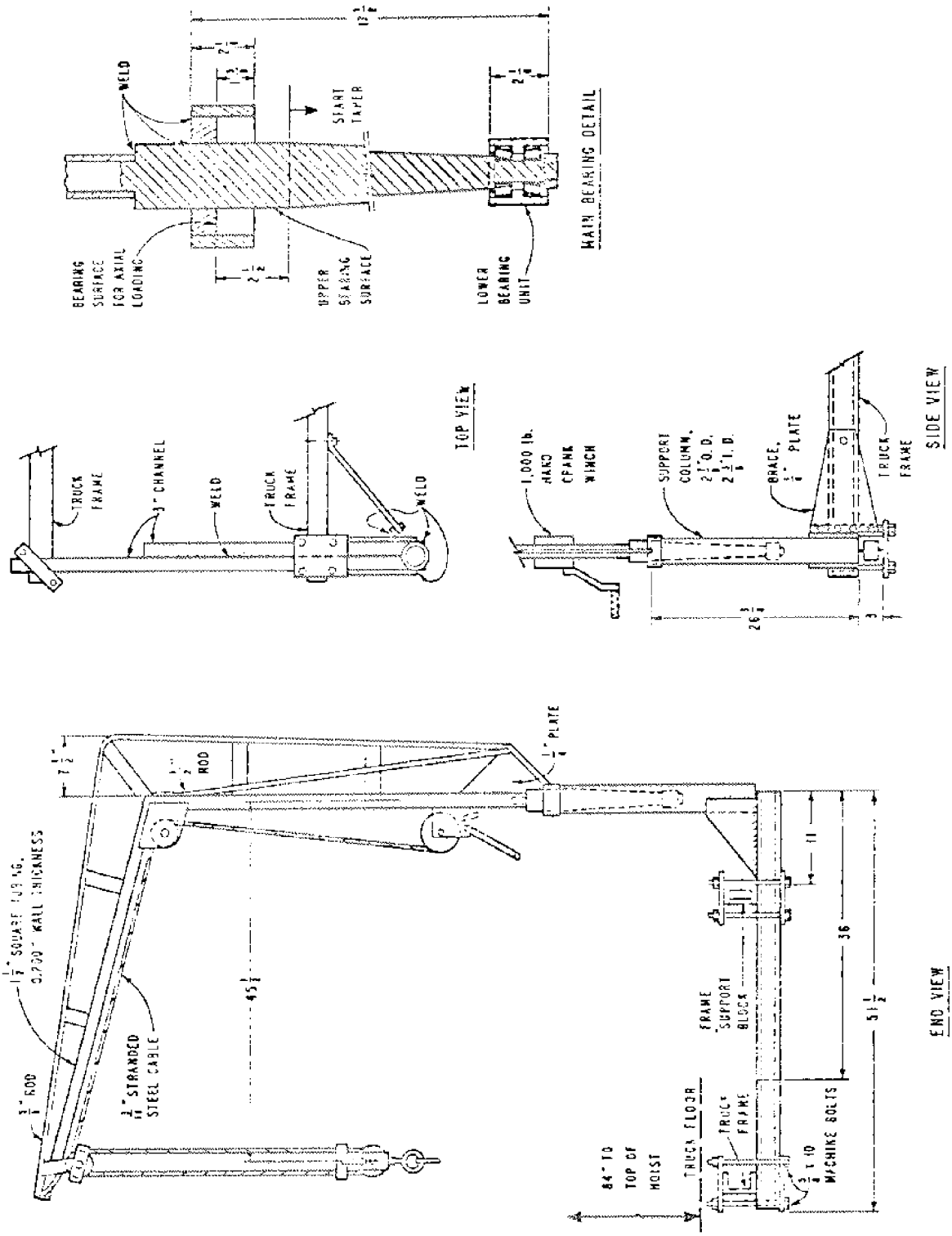

FIG. 66 Hoist designed and constructed to fit the pickup truck for the purpose of handling test equipment.

were sampled, then placed in the reshipper's cooler. The samples were iced. The truck returned to the College Park Laboratory where samples were taken of containers 3 and 4. The second technician then began processing the eight prerefrigeration samples. Containers 3 and 4 were then placed in the refrigerator. On the following and next succeeding morning a technician took two samples from each of the two containers in the reshipper's cooler, two samples from each of the containers in the College Park refrigerator and submitted these 8 samples to the laboratory for analysis. A total of 32 samples were thus generated.

Results of 1975 Tests

While on the boat, measurements were made of the salinity and water temperature of the harvest area. These values along with the antilog of the geometric mean of the initial bacterial levels are presented in Fig. 67. The salinity showed a marked increase throughout the summer, while water temperature increased to a maximum measured value of 83°F in early August, then decreased. No vertical water temperature variation was observed at any sampling point. Table 25 gives the data from which Figure 67 was plotted as well as harvest location.

Several attempts were made to correlate harvest location with bacterial count at harvest. Unfortunately, the data are too limited to define any trends in bacterial count with harvest location.

Appendix B contains a tabulation of the bacterial data from the 1975 on-board cooling studies. Samples taken at harvest were considered to be the zero hour for each container. The interval to the next three sample times was referred to the zero hour for the container being sampled. The average time for all the data to the second, third and fourth sample times was 6.3, 25.4 and 49.3. hours, respectively.

An analysis of variance was done on the 1975 on-board cooling data as the first step in analysis. Table 26 shows the analysis of variance (AOV) table for plate count while Table 27 shows the AOV table for total coliforms and Table 28 the AOV for the fecal coliforms.

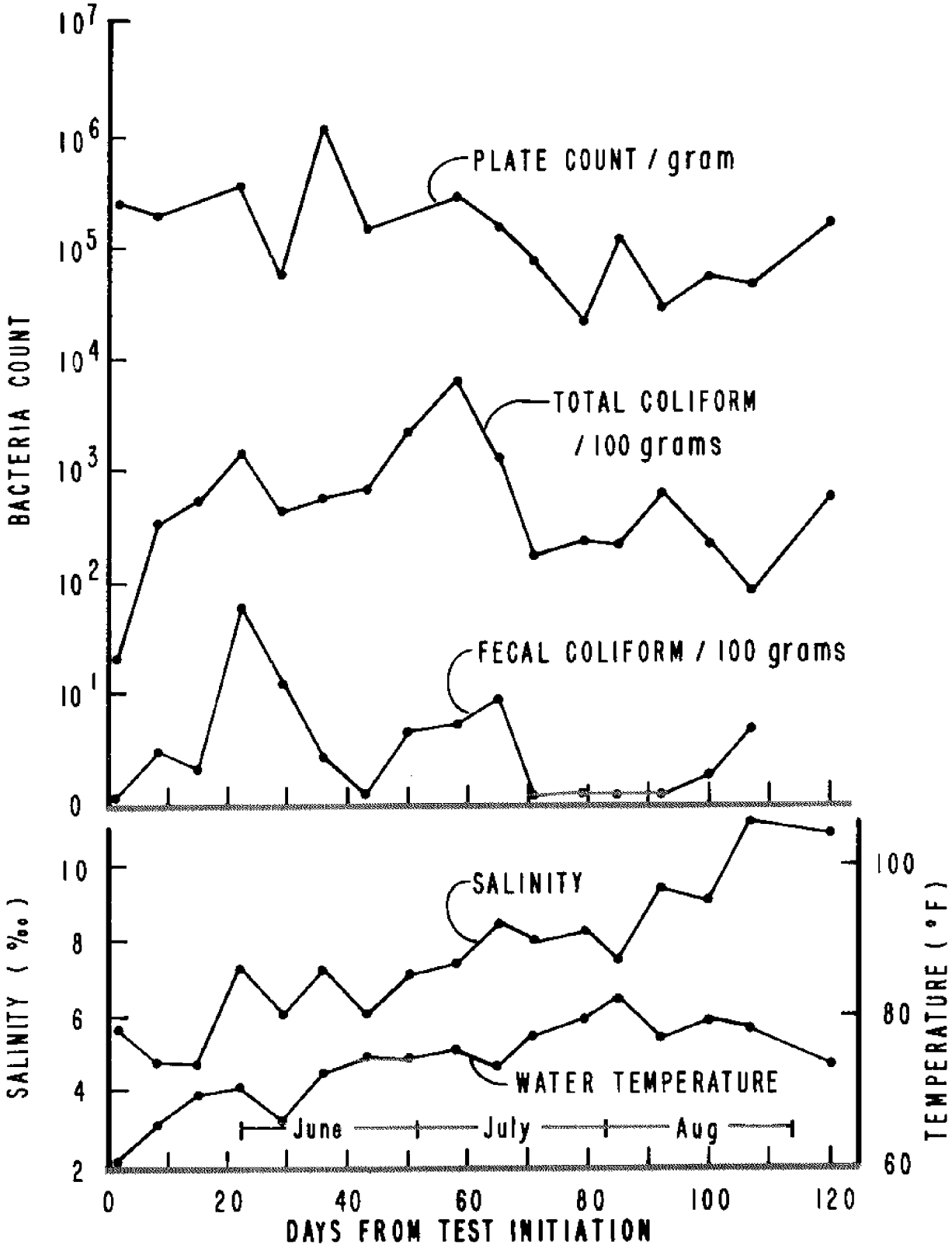

FIG. 67 Summary graph of initial bacterial levels, water temperature and salinity at all harvest locations.

TABLE 25. ON-BOARD COOLING STUDIES - SUMMARY: WATER TEMPERATURE, SALINITY, LOCATION AND AT-HARVEST BACTERIAL LEVELS

Test No.	Harvest Date (1975)	Days after first Test	Location	Water temperature, °F,	Salinity, ppt	Bacteria Level at Harvest, Antilog of Geometric Mean: Plate Count, Count/g	Total Coliforms, Count/100g	Fecal Coliforms, Count/100g
1	5-12	1	Three Sisters (Hoots Bar)	60	5.8	436,000	37	1.46
2	5-19	8	Thomas Point	66	4.8	307,000	561	4.92
3	5-26	15	Marshy Point	70	4.8	-	673	3.46
4	6-2	22	Saunder's Point	71	7.3	594,000	1,349	78.52
5	6-9	29	Under Bay Ridge	67	6.2	78,900	617	12.97
6	6-16	36	Dutchman's Point	73	7.3	1,618,000	750	4.58
7	6-23	43	Saunder's Point	75	6.1	137,000	851	1.46
8	6-30	50	Kent shore, at light	75	7.1	-	3,428	6.22
9	7-8	58	Kent, 2 miles above light	76	7.4	438,000	8,185	7.31
10	7-15	65	Kent Point	74	8.5	116,000	1,919	9.77
11	7-21	71	Saunder's Point	78	8.1	89,500	206	1.46
12	7-29	79	Kent Point	80	8.3	32,000	364	1.46
13	8-4	85	Middle Ground	83	7.5	101,000	353	1.46
14	8-11	92	Off Beverly Beach	78	9.4	43,100	791	1.46
15	8-19	100	Marshy Point	80	9.1	72,800	348	2.53
16	8-26	107	Off Beverly Beach	79	11.2	64,600	92	6.44
17	9-8	120	Middle Ground	74	11.0	166,000	726	-

Table 26 shows that only run (i.e., test); temperature (i.e., refrigerated or not refrigerated) and time since harvest are significant variables. The significance of runs was expected since each test came from a different location. However, the significance of runs is difficult to define in meaning. Obviously, location is involved, but other variables such as bottom type, salinity, etc. may also be compounded in this value.

TABLE 26. ANALYSIS OF VARIANCE OF PLATE COUNT DATA FOR THE 1975 ON-BOARD COOLING STUDIES

Source	SS	DF	MS	F	
Runs	45.483	13	3.499	20.83	*
Temp (F)	1.507	1	1.507	8.97	*
Cooling method (C)	.017	1	.017	0.10	
FXC	.089	1	.089	0.53	
Error 1	6.550	39	.168		
Time (T)	3.036	3	4.345	30.39	*
TXF	0.044	3	0.015	0.10	
TXC	0.659	3	0.220	1.54	
TXFXC	0.353	3	0.118	0.82	
Error 2	51.539	361	0.143		

*Indicates significant values at the 5 percent level.

Table 26 also shows cooling method (i.e., whether cold storage was provided by the commercial cooler or by the refrigerator in College Park) was not significant. Thus, both cooling systems provided equal control of bacterial growth as measured by plate count. Tables 27 and 28 show the same is true for total coliform and fecal coliform growth. Thus, the refrigerated and control samples placed in the commercial cooler and the paired samples placed in the laboratory cooler (refrigerator) can be averaged together, since there is no treatment difference contributed by the two cooling methods. Thus, the four treatments are reduced to two treatments: an on-board cooled and a control. Thus, the geometric mean for the on board refrigerated and control samples was calculated for each sample time. The antilog of

these values is plotted in Fig. 68 for the plate count data. Figs. 69 and 70 are similar plots for total coliform and fecal coliform data, respectively.

Table 26 indicates refrigerating the clams on-board the boat is significant. Fig. 68 shows that the refrigerated clams had a lower bacterial count than the control from harvest to the end of the 49 hour storage period. However, since there is no significant interaction between time and temperature the lines in Fig. 68 describing the geometric averages for the control and refrigerated samples are parallel from a statistical viewpoint. Since the refrigerated samples started at a significantly lower average value and the lines are parallel, there is some question whether the significant difference observed due to refrigeration occurred because the initial average (geometric) of the refrigerated samples was less than that of the controls or the effect is real. Since the slopes of the lines in Fig. 68 are the same (i.e., the bacterial growth rate for the refrigerated and control samples is the same) further doubt is cast on the real meaning of the significant difference observed.

Time after harvest was also a significant variable for plate count. This might be expected as the bacteria grow with time. All samples, including the controls, were refrigerated after approximately six hours out of the water. Thus, after six hours the bacterial growth rate of the refrigerated and control samples might be expected to be similar. However, because of the temperature difference experienced by the refrigerated and control samples during the first six hours after harvest some variation between these two treatments is expected during the first six hours. However, the experimental data indicates no detectable difference between bacterial growth rate, as measured by plate count, of refrigerated and control samples during the first six hour period.

Table 27 shows the AOV table for the total coliform data. Here only run and refrigerated versus control are significantly different. The difference in runs is probably attributable to the same variables as for runs in the plate count data which was discussed above. The effect of immediate refrigeration is shown in the significance of temperature. Fig. 69 shows that the samples refrigerated on board had

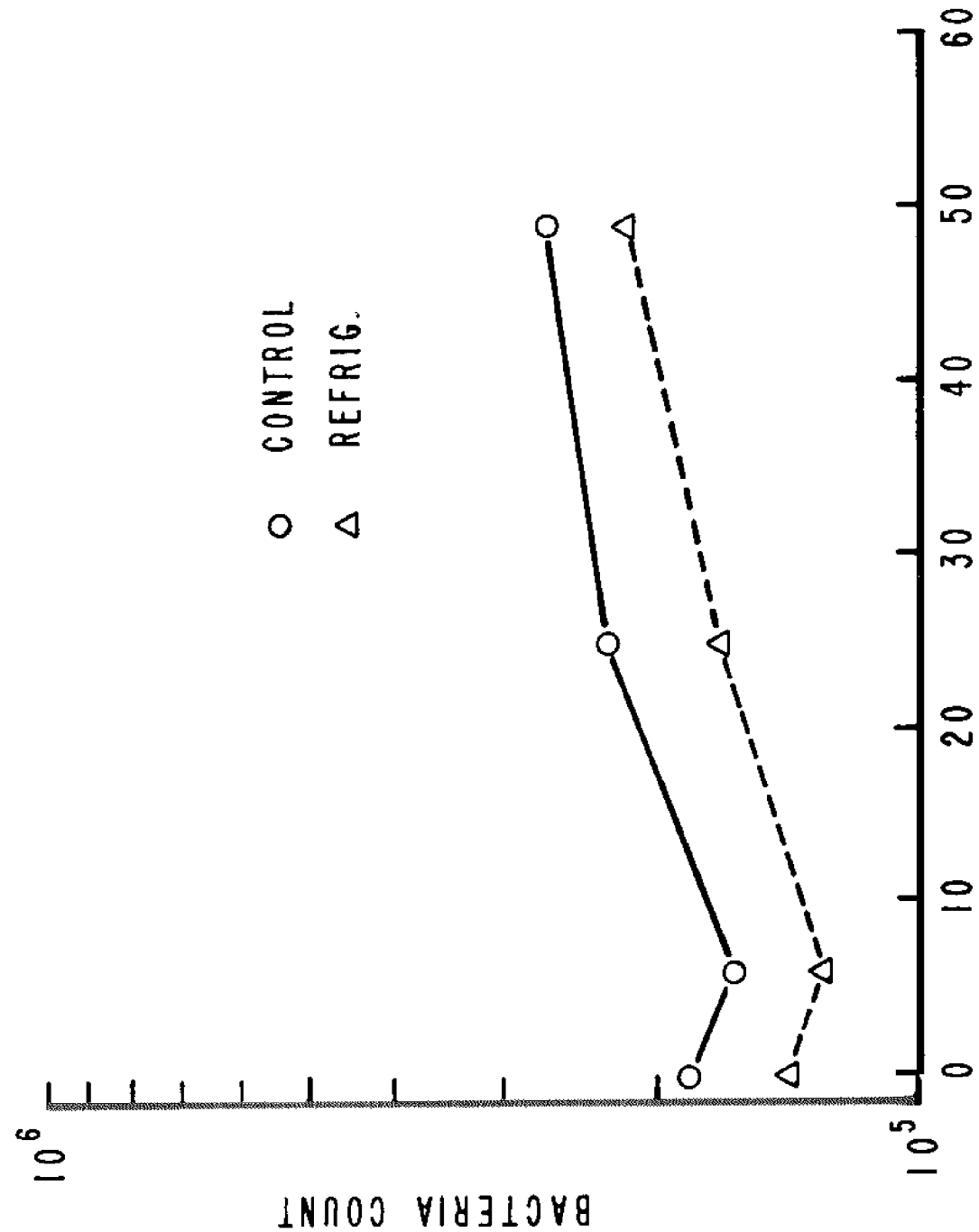

FIG. 68 Antilog of the geometric mean of plate count as a function of time since harvest.

a lower total coliform count than the controls. Statistically the two lines in Fig. 69 are parallel, but they are different from each other. Thus, the immediate refrigeration did reduce total coliform counts in these tests.

TABLE 27. ANALYSIS OF VARIANCE OF TOTAL COLIFORM DATA FROM ON-BOARD COOLING STUDIES

Source	SS	DF	MS	F	
Run	94.681	16	5.918	8.00	*
Temp (F)	4.007	1	4.007	5.42	*
Cooling method (C)	0.131	1	0.131	.18	
FXC	2.640	1	2.640	3.57	
Error 1	35.516	48	0.740		
Time (T)	0.096	3	0.032	0.06	
TXF	2.581	3	0.860	1.52	
TXC	2.940	3	0.980	1.73	
TXFXC	0.919	3	0.306	0.54	
Error 2	259.428	458	0.566		
Total		537			

*Indicates significant values at the 5 percent level.

It is also interesting to note that time and cooling method are not a significant variable for total coliform. Thus, the laboratory and commercial refrigerators gave the same results as noted previously. The lack of significance of time shows that there is no detectable growth of total coliform in the clams, either refrigerated or control lots, during the entire 49 hours of storage after harvest. Fig. 69 tends to indicate that the total coliform count in the control lots of clams does increase. However, because of the variability in the data the apparent increase in total coliform counts shown in Fig. 69 is not statistically significant.

Table 28 shows the AOV table for the fecal coliform data. Only runs and the interaction of temperature (F) and time after harvest (T) are significant statistically. The significance of runs has the same explanation as given for runs in the plate count data above.

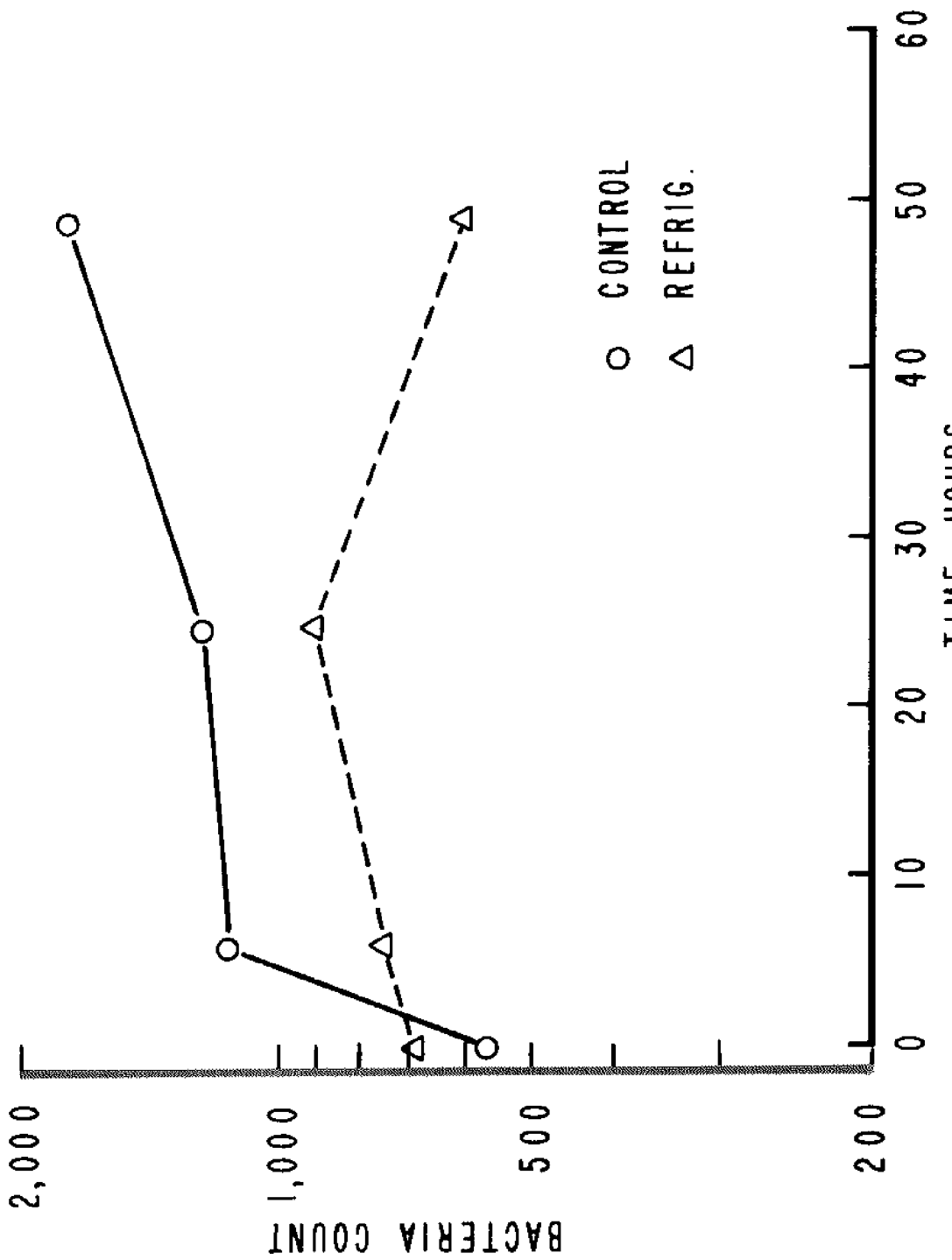

FIG. 69 Antilog of the geometric mean of total coliform count as a function of time since harvest.

TABLE 28. ANALYSIS OF VARIANCE TABLE FOR FECAL COLIFORM DATA FROM THE ON-BOARD COOLING STUDIES

Source	SS	DF	MS	F	
Runs	76.289	15	5.086	6.75	*
Temp (F)	.145	1	.145	0.19	
Cooling method (C)	.019	1	.019	0.025	
FXC	.034	1	.034	0.045	
Error 1	33.917	45	.754		
Time (T)	0.012	3	.004	0.008	
TXF	5.877	3	1.959	4.13	*
TXC	1.030	3	0.3433	0.72	
TXFXC	1.408	3	0.4693	0.99	
Error 2	203.896	430	0.47418		

*Indicates significant values at the 5 percent level.

The fact that temperature, cooling method and time are not individually significant but the interaction of time and temperature is requires further analysis. Lack of significance of cooling method shows that the laboratory and commercial refrigeration systems gave equal results for fecal coliform data, as for plate count and total coliform data. To further determine the meaning of the temperature-time interaction, a SNK (Student-Neuman-Kool) test was run to determine which means were different from each other. The results of this test is shown in Table 29. The differences between various values can be ascertained by comparing superscripts in Table 29 and observing the plot of the data, Fig. 70. Looking across time for the control samples, Table 29, the zero hour value is significantly different from the 6, 25 and 49 hour values. The 6 hour value is significantly different than the zero and 49 hour values only. The 25 hour value is significantly different than only the 0 and 49 hour values, while the 49 hour value is significantly different from only the 0 and 25 hour values. A similar comparison can be done for the control samples.

Comparing the refrigerated mean with control mean at each sample time shows there is a significant difference only at the zero and six hour points.

In general, the fecal coliform data shows that during the first six hour period the fecal coliform in the control sample (unrefrigerated) grew rapidly while the clams subjected to immediate on-board cooling show little or no fecal coliform growth. At approximately six hours after harvest the control samples were also placed under refrigeration. Looking at the initial refrigeration period for each set of clams, the 0 to 6 hour period for the refrigerated container and the 6 to 25 hour period for the controls, Fig. 70, indicates there is a decrease in fecal coliform count during this period. Table 29 confirms that it is statistically significant for the control but not the refrigerated samples. The reason for this decrease is unclear, although one can speculate that it is caused by temperature shock experienced by the fecal coliform bacteria.

TABLE 29. RESULTS OF COMPARISON TESTS ON GEOMETRIC MEANS OF THE FECAL COLIFORM DATA

	Hours after Harvest			
	0	6	25	49
Control	0.473^{d}	0.953^{ab}	0.779^{bc}	1.061^{a}
Refrigerated	0.745^{bc}	0.621^{cd}	0.798^{bc}	0.960^{ab}

Superscript indicate which values are significantly different from each other. Values with at least one common letter in the superscript are not significantly different.

During the initial six hour period the unrefrigerated clams experienced rapid fecal coliform growth while the on board refrigerated sample actually experienced a decrease in fecal coliform count. However, once the control samples were placed under refrigeration (after 6 hours) there was a decrease in count in the controls caused by refrigeration plus there was a fecal coliform growth experienced in the clams refrigerated on-board between the 6 and 25 hour sample points.

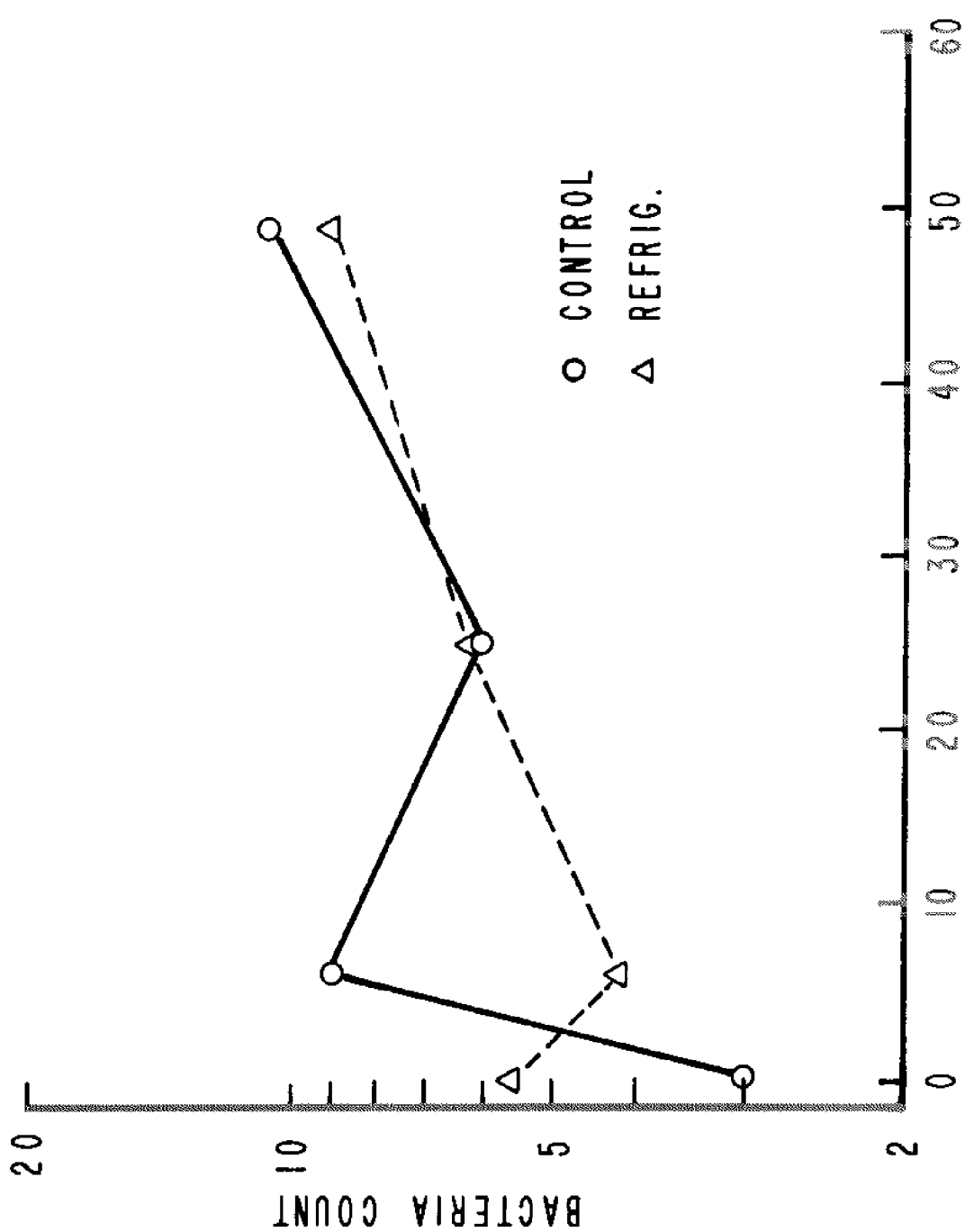

FIG. 70 Antilog of the geometric mean of fecal coliform count as a function of time since harvest.

The combination of these two factors caused the fecal coliform count at the 25 and 49 hour sample points to show no significant difference between refrigerated and control samples. Thus, on-board refrigeration does significantly lower fecal coliform counts compared to non-refrigerated. However, refrigerating the controls after six hours plus growth in the on-board refrigerated samples during the 6 to 25 hour period results in similar counts in the control and on-board refrigerated sample about 25 hours after harvest.

Thus, the effectiveness of on-board cooling depends on when sampling takes place and on relative time between harvest and when the non-refrigerated clams are placed under refrigeration. Data presented indicate six hours between harvest and placing containers under refrigeration leads to similar fecal coliform counts after about 25 hours. Increasing the time between harvest and placing the clams under refrigeration to more than six hours may change this result significantly due to the more rapid growth rate of fecal coliform bacteria in unrefrigerated clams. Even if clams are held under unrefrigerated conditions for six hours or less, Fig. 70 leaves open the question of what fecal coliform count will be in these clams if storage is extended beyond 49 hours.

Conclusions

The following conclusions can be drawn from the on board cooling data presented in this section:

1. Icing samples and transporting them back to the laboratory for bacterial analysis produced results similar to starting analysis on-board the harvest boat in tests conducted in this study.

2. In monitoring bacterial growth over the first one hour after harvest the following were noted:

a) Plate count increased a detectable amount when the clams were held under conditions currently used in the industry. Clams refrigerated immediately after harvest showed no detectable change in plate count during the first one hour after harvest.

b) Total coliform multiplied at statistically detectable rates during the first one hour after harvest in these tests whether they received immediate cooling or were held under current industry practices.

c) One hour was not long enough to statistically detect a change in fecal coliform population in soft clams when the clams were held as currently done in the industry or were refrigerated immediately after harvest. This conclusion is based on the small number of paired samples (i.e., 8 samples) available in these tests.

3. Water and clam temperatures at harvest in Maryland often exceed the temperature necessary for rapid multiplication of bacteria.

4. Plate count, total coliform and fecal coliform increase similarly in a commercial cold box as they do in a controlled laboratory cooler.

5. Plate count increased at a similar rate in the soft clams tested herein whether the clams were cooled rapidly immediately upon harvest or were placed under refrigeration in a cold box six hours after harvest.

6. Immediate on-board cooling reduced total coliform counts in soft shell clams over the 49 hour storage period of these tests compared to conventional industry practice. Over the 49 hour storage period total coliform count remained constant once the clams were cooled to 40°-45°F.

7. Fecal coliform counts in these tests appeared to multiply rapidly during the unrefrigerated period between harvest and placement in a cold storage room.

8. Fecal coliform counts in the control tests decreased immediately after soft clams were placed under refrigeration, possibily due to temperature shock.

9. In these tests the unrefrigerated period between harvest and cold storage did not exceed about six hours. Under these conditions fecal coliform growth during unrefrigerated and subsequent refrigerated storage and the initial decrease in count due to placement under refrigeration combine to produce about equal counts after approximately 25 hours of storage. This equal count was maintained up to at least 49 hours of storage.

VI. ENGINEERING ASPECTS OF THE SOFT SHELL CLAM INDUSTRY; DESCRIPTION OF EQUIPMENT AND PROCEDURES

There are two predominant areas of soft clam production on the East Coast: Maine and the Chesapeake Bay. There are several differences between the two resources. Most of Maine's clams are found and harvested from inner tidal zones while all of Maryland's clams are found in subtidal waters. The clams of Maine are dug by hand at low tide whereas the Maryland clam is dredged mechanically and hydraulically from a boat. The colder environment of Maine dictates that three or more years are necessary for a clam to reach harvestable size. Maryland is the southern limit of commercial quantities (warmer water being the limiting factor), but Maryland clams grow to harvest size in less than two years. They are frequently subjected to thermal stress-related mortalities resulting in a dynamic clam population.

The clam begins life as a free floating larva. With further development they are able to attach to sediments and vegetation or release themselves at will to drift with the currents to a more favorable habitat. At a length of one inch the clam establishes a permanent burrow in the bottom. The depth below the soil-water interface depends on the size of the clam and the nature of the bottom sediments. The depth to which they burrow will be approximately 2 1/2 times their longest diameter (Dow, 1961), but this depth can be increased to four times the length of the shell (Hanks, 1966). Limited vertical movement is possible to adjust for changing bottom levels, increased size or reburrowing after having been dislodged. A siphon (neck or snout) is extended to just above the surface of the bottom to feed and discharge wastes.

Maryland soft clams were essentially unharvestable until the development of the escalator dredge by Fletcher Hanks of Talbot County during 1950 and 1951. It was first used commercially by seven licensed watermen in 1952 (Manning, 1957). The 1955 General Assembly of Maryland enacted legislation to license dredges and operators, restrict areas of operation, restrict dredge size and provide a 10 cents per bushel tax to fund clam related research.

Escalator Dredge and Boat

Figure 71 shows a schematic view of the hydraulic escalator dredge used for harvesting Maryland soft shell clams. It consists of a water distribution manifold, a dredge head, frame and conveyor. The dredge head operates below the bottom surface a sufficient distance to be below the clams. Water pumped through the manifold erodes away the bottom ahead of the dredge and washes the sediment and clams into the dredge. Water flow through the dredge head carries the sediment and clams into the conveyor. The chain mesh belt allows bottom soil to pass through it but retains the clams. The conveyor carries the clams out of the water and past the side of the boat. The dredge operator picks the clams off the conveyor as they move past and allows empty shells, clams below legal size, stones and other debris to pass over the end of the conveyor back into the water. Bottom soil and debris settles back into the trench formed by the dredge as it is forced along the bottom by the boat. This partially refills the trench and provides an easy place for the undersized clams to reburrow.

Dredge Construction

Fig. 72 shows details of the dredge water manifold. Water is pumped down the hose (upper right of Fig. 72) into a manifold. The manifold distributes the water to a series of nozzles usually formed from straight lengths of 1/2 or 3/4 inch diameter black or galvanized pipe. The spacing and number vary slightly from dredge to dredge, but usually there are eight to ten nozzles on the manifold. Nozzle length varies some but is usually 4 to 6 inches.

The angle between the vertical and the nozzle can be changed to suit operating conditions of dredging speed, bottom type, etc. This can be accomplished by the rod attached to the top center of the manifold, Fig. 72. On some dredges this lever can be controlled from the boat during dredging while in others the dredge must be lifted out of the water to vary nozzle angle.

The dredge head is also shown in Fig. 72. The dredge head, or scoop, is limited to 36 inches width by the water manifold, the maximum

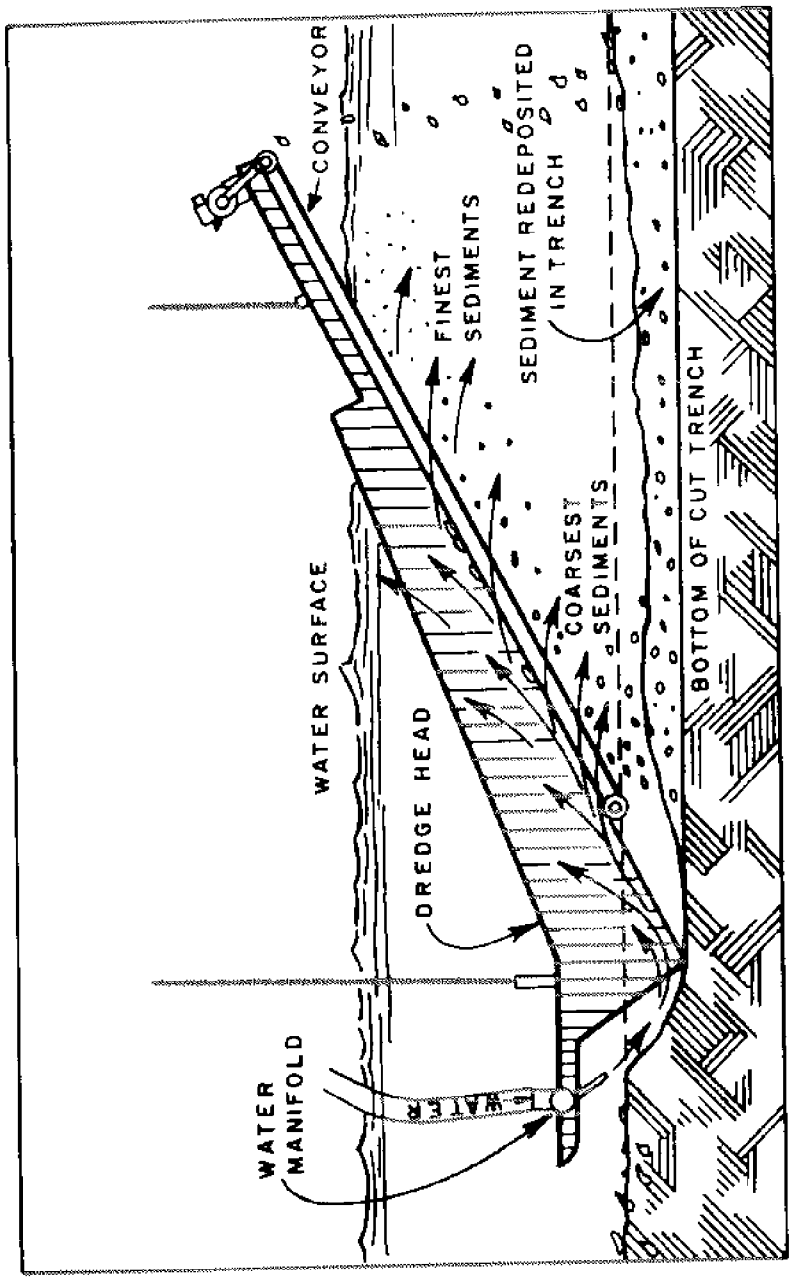

FIG. 71 Schematic view of the soft clam hydraulic escalator dredge (Manning, 1957).

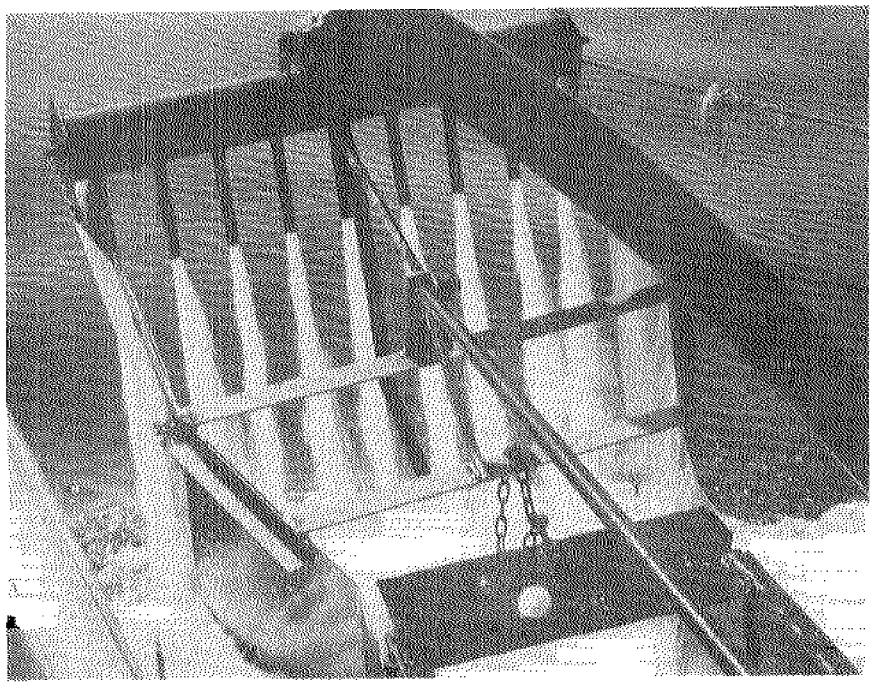

FIG. 72 Water jets and scoop as viewed from the boat deck when conveyor is in the up or stowed position.

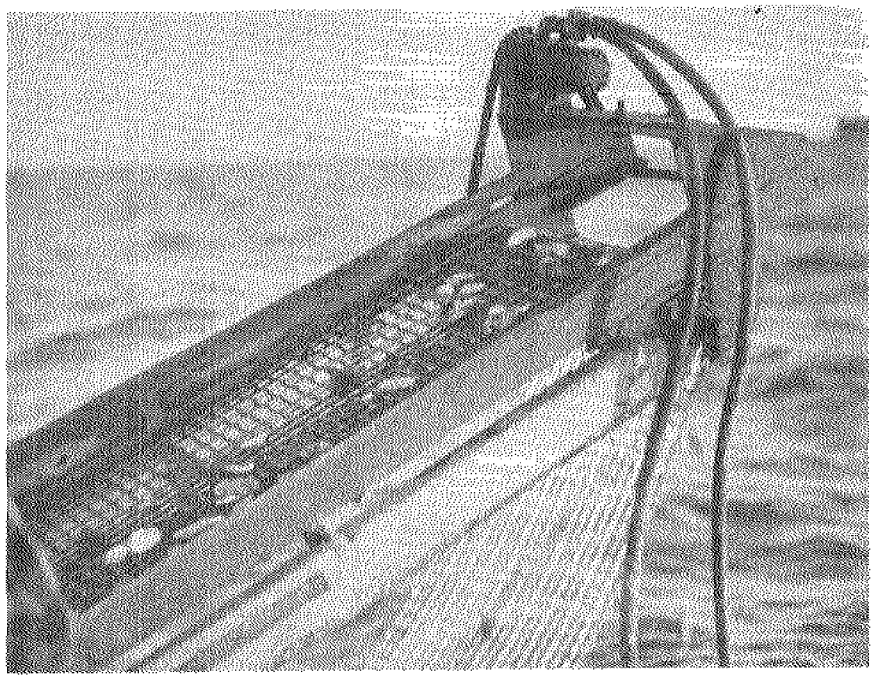

FIG. 73 Conveyor chain and hydraulic motor drive for escalator dredge.

legal length of which is 36 inches in Maryland. The head has a narrowing transition section which forces the dug clams onto the narrower conveyor. The water flow from the nozzles is sufficient to carry all the clams and sediment onto the conveyor chain.

The conveyor chain is usually 12 to 18 inches in width and is made of square metal links. The mesh size is at least one inch square to allow soil and small clams to pass through the chain. Most watermen use steel chain, but due to corrosion some feel the increased life of stainless steel outweighs its increased cost. Fig. 73 shows a typical chain.

The conveyor chain, water manifold and dredge head are held together and supported by a steel frame. Frame design varies from dredge to dredge but generally is constructed of welded steel. Its length also varies depending on the maximum depth of water it will be used in. However, a long dredge will be 35 feet between centers of the conveyor shafts. Typically, the frame has an arch in the center such that when both ends of the dredge are on a flat surface the center of the dredge may be as much as a foot above the flat surface. Each dredge is designed differently since the dredges are handmade by a waterman or by a waterman working with a machine shop. Some dredges have no arch at all. The reason for the arch is not clear; different watermen have different views as to advantages.

The dredge conveyor chain is driven by an electric or hydraulic motor, Fig. 73. Hydraulics, Figs. 73 and 74, are gaining increasing popularity due to their resistance to salt air corrosion, easily varied speed and torque, small size, low maintenance, quiet operation and ability to be easily reversed (a significant advantage when the chain gets caught in the bottom). These advantages seem to offset the somewhat higher cost of hydraulic drives over electric motor drives. A few watermen also use a small air cooled engine on the dredge to drive the conveyor chain.

Fairly high sides must be placed along the conveyor and sides of the head to keep the clams on the dredge, especially along the submerged parts of the dredge. Some dredges have the dredge head and underwater portions of the conveyor completely covered. These sides

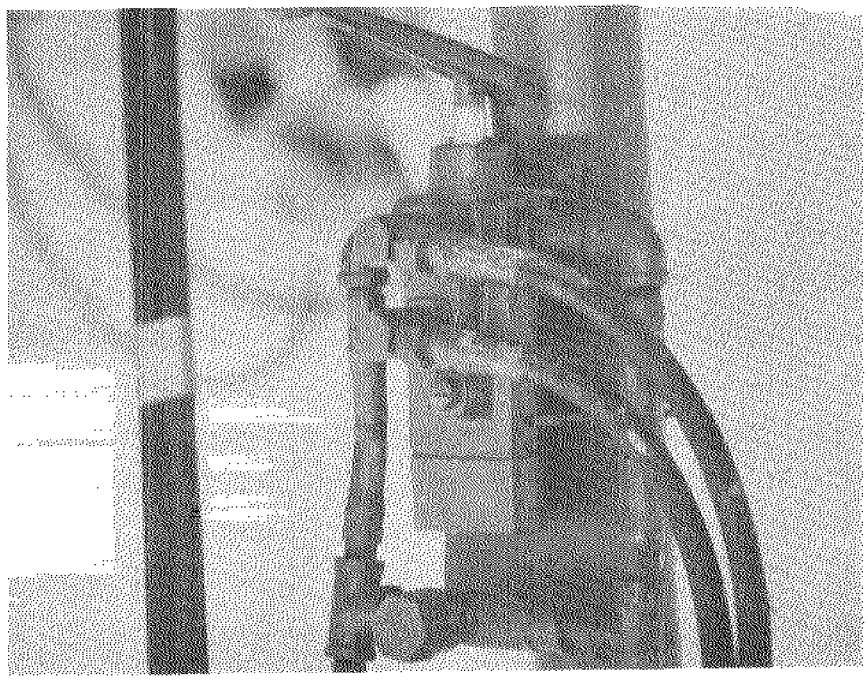

FIG. 74 Hydraulic controls for the dredge power unit. Below the reversing spool valve is a by-pass valve for conveyor speed control.

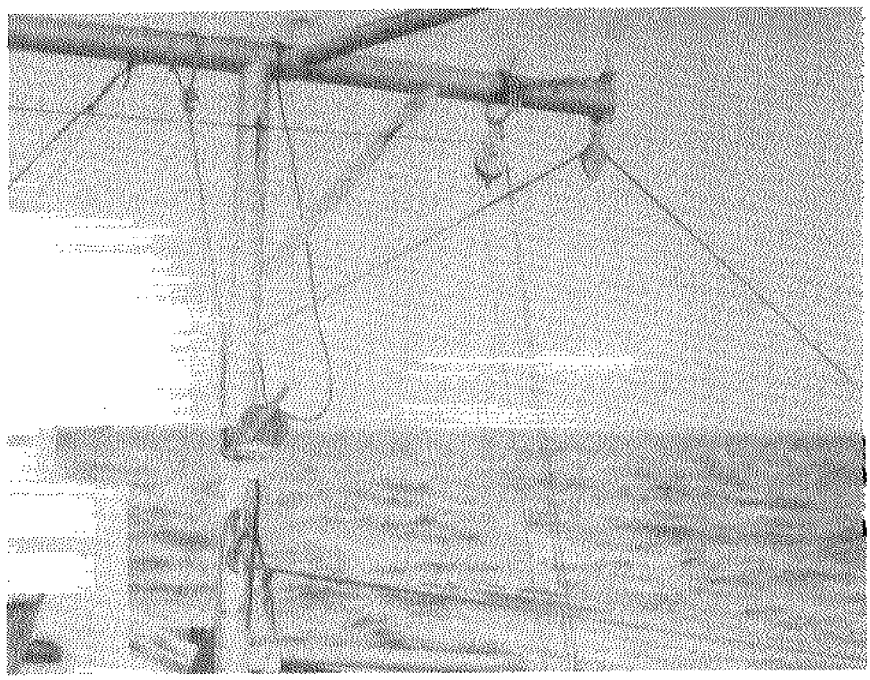

FIG. 75 Forward stanchion and cable assemblies used to carry the majority of the weight of the dredge.

(and cover) may be made of sheet metal, plywood or a wire mesh material.

The dredge is supported from the boat at two points by cable assemblies. The rear support is adjusted only when stowing the dredge for travel. The front cable support, or stanchion (Fig. 75) carries about 70 percent of the total dredge weight and must be adjustable over a large vertical distance. Vertical adjustment is usually obtained by an electrical power winch (Fig. 76) although a hydraulically powered winch could be used. However, a hydraulic winch drive requires the engine powering the hydraulic system to be running whenever the dredge is raised or lowered. With an electrical system some dredge movement is possible by drawing power from the battery. The front winch drive must be controllable from a forward position near the winch (for stowing the dredge) as well as back at the operator's station so that the dredge depth can be adjusted easily while dredging.

The large volume of water required for washing the clams from the bottom is provided by a centrifugal pump driven by an auxiliary engine. Engine, pump and suction line are situated on the left side of the boat to offset the weight of the dredge (located outboard on the right side) as well as to draw water from a point away from the area of dredging. Fig. 77 shows a typical direct coupled system as used on a clam dredge boat. Although pumps used vary considerably, a centrifugal pump, usually having a 6 inch diameter inlet and 4 inch diameter outlet, is most common. The 6 inch inlet pipe is formed into an inverted U-shape and coupled to the pump with a rotatable connection of some type. During operation the inlet is placed in the position shown in Fig. 77. When the pump is not in operation, the inlet is rotated upward so the entire inlet pipe is inside the boat railing. This allows docking of the boat without damage to the inlet pipe. (The dredge is on the other side of the boat so the waterman cannot get up to the dock on that side.) Although the example shown in Fig. 77 is direct coupled to the pump, some boats use belt or gear drives to match engine output shaft speed to pump requirements.

The pump motor may be either air or water cooled. If water cooled, water is usually drawn from the dredge pump discharge, passed through the engine once and piped overboard. Air cooled engines

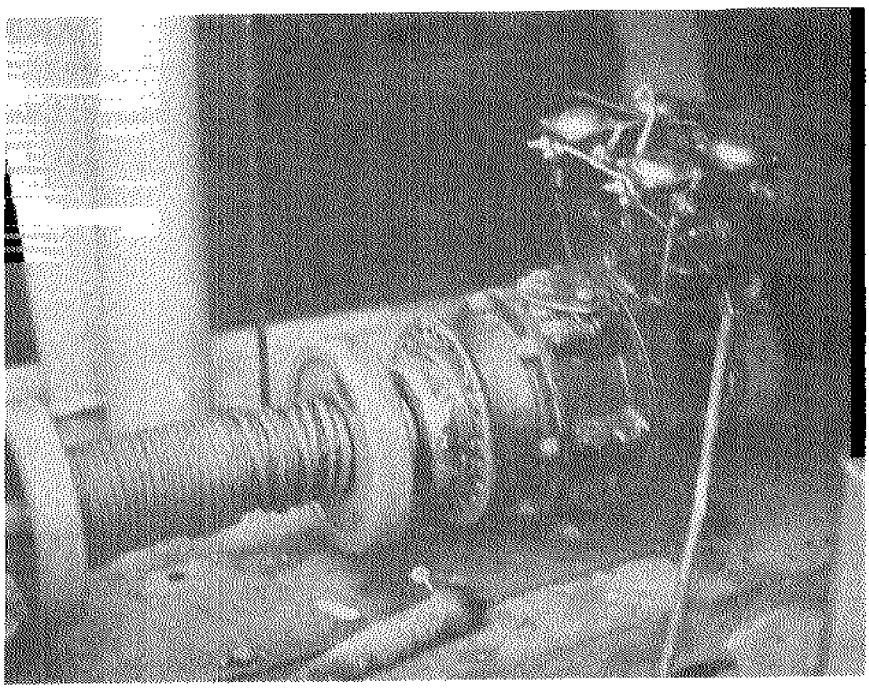

FIG. 76 Electric winch used to raise and lower the foreward end of the dredge.

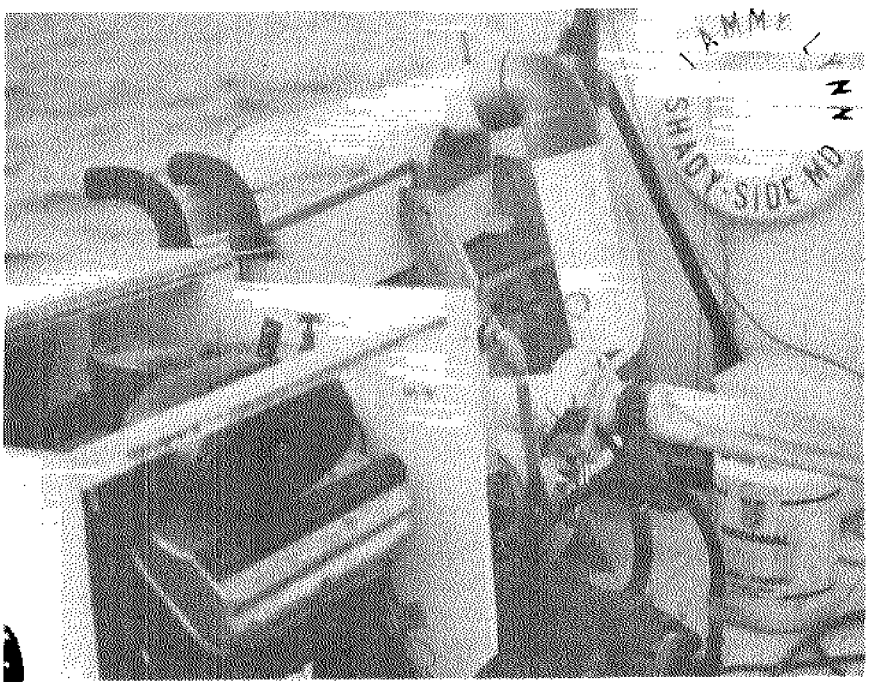

FIG. 77 Typical dredge pump direct coupled to internal combustion engine. Pump intake is shown in the operating position.

utilize a radiator and a recirculating water cooling system similar to that used in an automobile. Water cooled systems provide quieter operation and an easily adjustable cooling rate when compared to the air cooled engines. However, water cooled engines cannot be operated any length of time without the pump running and the brackish water corrodes the engine more rapidly.

The pump and its drive motor are mounted on the port (left) side of the dredge boat to provide a counterweight for the dredge which is mounted outboard on the starboard side. Additional weight is sometimes needed on the port side to increase boat stability.

The boat and dredge must be compatible. The dredge has to be of sufficient length to reach the bottom in the deeper waters without excessive conveyor incline. Dredge strength must be sufficient to withstand its own weight and dredging forces but not so heavy as to hinder boat operation. The boat must be capable of supporting the weight of the dredge and its support rigging, an auxiliary pump engine and perhaps counterweights. Sufficient deck area must be available to stow empty and full baskets and provide work space adjacent to the upper or rearmost end of the dredge. Boat size should be sufficient for stability during dredging and seaworthiness in open water, yet within reason relative to initial and operating costs and maneuverability in shallow water.

Most clam dredge boats used in the Chesapeake are of bay built dead rise construction. Usually these boats have washboards about 12 inches wide in place on the boat. The dredge is mounted on the starboard side and stowed on the washboard for transport and docking.

Operation of the Clam Dredge

Upon reaching the harvest location the dredge tie down ropes are unfastened; the dredge is raised from its stowed position and moved outward beyond the edge of the boat.

The scoop or digging end is lowered by the lift winch until the water manifold is below water level. The hold-out bar is dropped but no lines adjusted at this time. The suction pipe to the pump is rotated overboard into the water and the pump engine started.

Several means are used to prime the pump. A line from the intake manifold of the pump engine is run to a transparent reservoir then to the top of the suction pipe. A valve in the line serves as a control. Vacuum is applied to the suction pipe until water is observed in the reservoir. The valve is then immediately closed to prevent water entering the engine. A system requiring more labor uses a manual vacuum pump on the suction line. Another method uses a second, smaller self-priming pump to pump water into the larger pump.

Once water is being pumped to the jet manifold, the dredge conveyor is started and the dredge lowered to just above the bottom. The belly rope and hold-out line are adjusted to hold the dredge in line with the boat. Any significant raising or lowering of the dredge will necessitate readjustment of the belly and hold-out lines. With all equipment operating, the boat transmission is engaged and the dredge lowered into the bottom. The depth of the scoop in the bottom can only be guessed. When depth is too shallow, snouts will be cut off and clams will be cut in half perpendicular to the snout. Both of these problems are visible in clams coming up the conveyor. The presence of whole clams will indicate sufficient depth. Excessive dredging depth is less apparent unless forward motion is restricted and the boat advances relative to the dredge. Other restrictions to dredging are hard bottom, incorrect alignment of the water jets or an object on the bottom.

During active dredging the operator leans across the washboard (a very tiring position to work in) and visually scans the entire load of material on the conveyor to determine correctness of dredge depth and to retrieve live, healthy, legal clams. Retrieving harvestable clams from the conveyor must be done quickly as time does not permit a second glance or the physical measurement of clams unless the clam population is very low. The nature of the bottom determines the difficulty in locating harvestable clams on the conveyor, Fig. 78. In sand bottom with no residual shells, the conveyor is empty of extraneous matter. In areas of heavy shell residue, the depth of empty shells on the conveyor has been observed to approach two inches, thus, impeding visual identification of live clams. Some bottom has sufficient binder

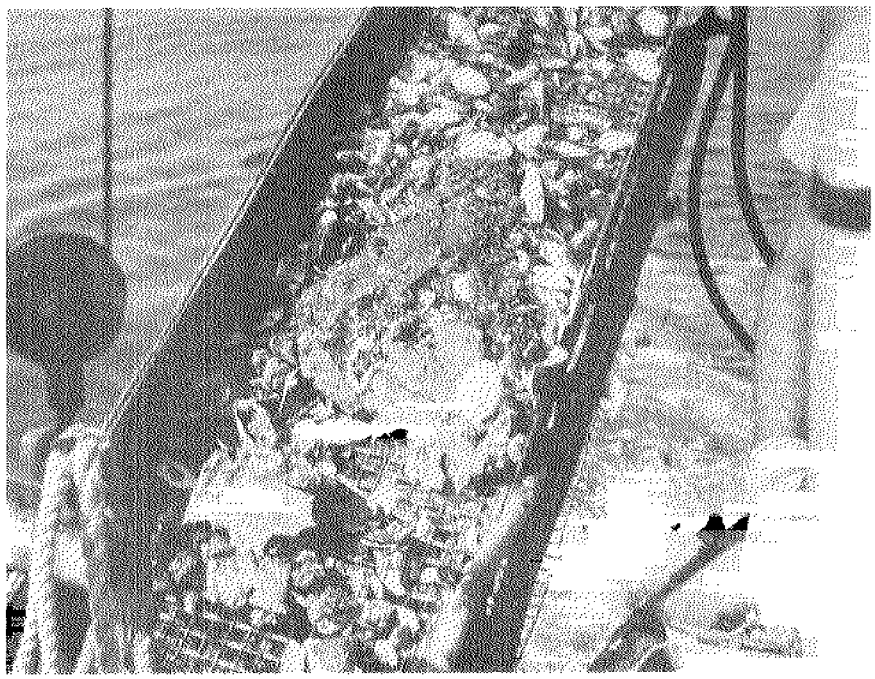

FIG. 78 Example of material, other than harvestable clams, which is brought up by the dredge.

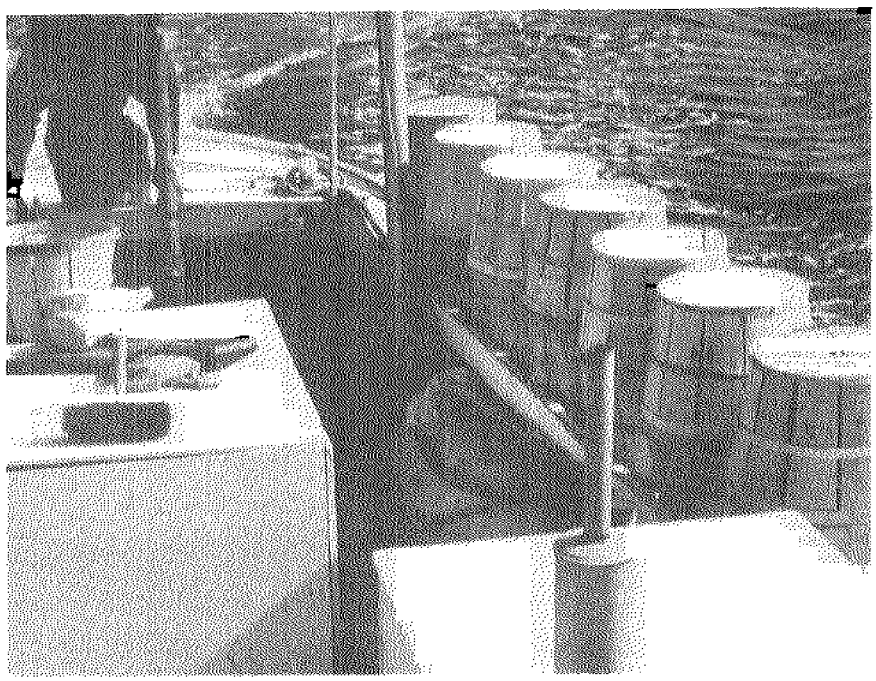

FIG. 79 Full clam baskets stowed on the port wash board and shaded by inverted cover-baskets.

in it that large chunks are brought up with the conveyor. Aquatic plants were not observed on the conveyor in any quantity.

The greater portion of the dredge operator's time is spent visually scanning the contents of the moving conveyor for harvestable clams. These are picked manually with one or both hands and laced in either a wooden bushel basket or a smaller container, which when filled is then dumped into the wooden basket. The thin fragile shell of the clam requires that clams be placed into the container, as even a 12 inch drop will cause breakage of some clams. The full basket is carried to a storage location either on the fantail, left washboard (Fig. 79) or interior deck.

Maryland regulations require full clam baskets to be protected from direct rays of the sun and kept away from high temperature areas of the boat (e.g., near the engine exhaust). Current practice is to invert an empty basket over each full basket to provide shading, Fig. 79.

The surface level of freshly filled clam baskets always recedes as the clams discharge water and individually reduce their volume. Thus, it is the industry practice for the dredge operator to "top off" (i.e., add clams to the basket) about one hour after original filling and again at dockside. This provides a full basket to the buyer.

In the absence of wind, waves, or currents the operator usually dredges in a wide circle to the right as visibility to the left front is blocked by the cabin. If waves exist, the boat must be operated perpendicular to the waves. A strong tide from the rear will possibly wash clams from the dredge. Wind from the rear helps propel the boat and dredge through stiff bottom. Seas of two feet or more inhibit dredging. The wakes of ocean going freighters have caught clammers by surprise resulting in severe damage to the dredge and rigging.

Nearly all dredge boats have a dual set of controls: one located at the operator's station near the conveyor and a second in the boat cabin. The set near the operator's station allows convenient control of the boat and dredge during active dredging. Thus, dredge depth and conveyor speed, boat speed and boat steering and gear changing are convenient to the operator. When large objects on the bottom jam the conveyor, the belt can be freed by reversing it without the operator moving from his station.

Dredge Operating Parameters

The conveyor is often designed with an easily variable speed. Speed used appears to be a function of bottom type, boat speed and operator preference. A conveyor speed of 1.87 feet per second was measured on one boat.

Many different pumps are used on soft clam dredges. Time and availability of measuring equipment did not permit detailed analysis of pump operating parameters. However, Mathieson and DeRocher (1974) did a detailed analysis of one pumping system. Their system provided 575 gpm at 21 psi nozzle pressure. Generally, Maryland clam dredges use a centrifugal pump with a 6 inch inlet and 4 inch outlet. These pumps usually operate at about 2400 rpm and require approximately 30 horsepower.

Most clam dredging systems utilize two internal combustion engines: one to propel the boat and a second to pump water for dredging and to provide hydraulic power if needed. Manning and McIntosh (1960) equipped a clam boat with a variable pitch propeller and powered the water pump directly from the push motor, eliminating the second auxiliary engine. Using this arrangement they were able to attain dredging speeds ranging from 0.15 to 0.55 mph depending on the combination of pitch and/or engine speed used. This compares with commercial dredging rates reported by Manning (1957) of 1200 to 1300 square feet per hour which, if one assumes a 30 inch wide dredge head, converts to speeds of 0.20 to 0.21 mph. Manning and McIntosh (1960) determined that for a given engine rpm an increase in pitch resulted in an increase in dredging rate, but only up to a point after which the rate dropped off. Dredging rate was shown to increase at an increasing rate as engine rpm was increased with a resultant increase in both thrust and water pressure. Over the ranges of engine speed and pitch tested, a fuel savings of 26% to 37% was realized by using a single engine versus a dual engine. For single engine dredging fuel cost per acre was reduced as engine speed was increased. Flexibility of operation was not impaired by the use of a single engine and variable pitch propeller.

Several measurements were made of the forward speed of dredging during the 1975 on-board cooling studies. A pointed rod was forced into the bottom just off the stern of the boat. A string having knots tied at known intervals was attached to the rod. The time required for the boat to progress the distance between any two knots was t med with a stopwatch. The rod was subsequently retrieved by a heavy rope attached to the pole just above the bottom. Type of bottom was not determined. Measured speeds ranged from 0.23 to 0.37 mph.

The theoretical rate of harvest in bu/hr. is a function of clam density and harvest speed. Assuming a 30 inch scoop width operating at a rate of 1200 ft^2 per hour, 100 bushels per acre will translate into a harvest rate of 2.75 bushels per hour. A waterman could begin harvest by 5:30 AM and catch the current 15 bushel limit before the noon summertime cutoff. Localized densities of 600 bu/ac (Manning, 1957) and 300 bu/ac (Pfitzenmeyer and Drobeck, 1963) have been measured. Speed of dredging has a practical upper limit in bottom having a heavy shell residual due to the amount of material coming over the conveyor.

The demands on the waterman's time include preparation, steaming, dredge engagement, harvesting, dredge retrieval, return trip, unloading, maintenance and preparation. Most preparation is done the previous day during daylight. Steaming time ranges between 20 minutes and 2 hours. Dredge engagement has been measured at between 6 and 8 minutes depending on whether 1 or 2 men are working. Securing the dredge after use requires 6 minutes or more depending on the amount of time used to wash down equipment. The time required to dock, unload 15 bushels then clear the dock was measured at 3 to 6 minutes.

Effect of Shading on Soft Shell Clam Temperature

Present Maryland regulations require watermen to cover full clam baskets with an empty basket or to provide adequate shading of the clams from direct sunlight. Fig. 80 shows the effect of exposing clams to direct sunlight. Temperature of the clams was measured through insertion of a thermocouple in the foot opening. Initial clam temperature (shaded with an inverted basket) was $84^{\circ}F$. After 25 minutes of direct exposure to sunlight, clam temperature had increased to $100^{\circ}F$.

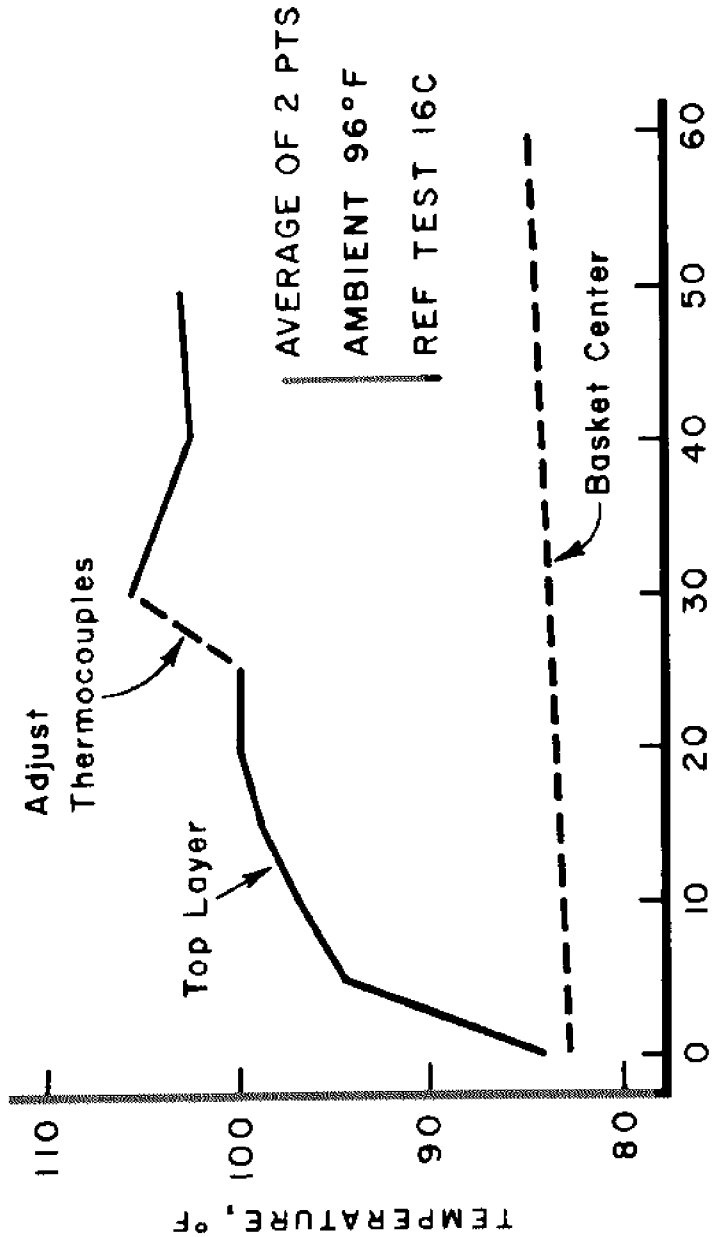

FIG. 80 Result of exposing soft clam shellstock to direct sunlight.

The foot opening of the clam was observed to have opened. The clam was touched to check thermocouple position, the clam closed and the temperature increased to 105.5°F but lessened as the clam again opened.

Fig. 81 shows the effect of keeping an inverted basket over the full basket. Over a period of 50 minutes in 80°F ambient air the uncovered clams were warmed to 96.5°F, whereas the top layer of clams in the covered basket increased in temperature to 83.5°F. Temperature of the center of the two baskets was fairly stable whether covered or not over the 50 minute period.

Data in both Figs. 80 and 81 strongly support the desirability of providing adequate protection for the clams from exposure to direct sunlight. Obviously, the temperature of the top layer is influenced the most. Data from the environmental chambers combined with data in Figs. 80 and 81 strongly suggests that bacterial growth will be particularly rapid in the top layer. During subsequent handling and processing this layer may contaminate many other clams.

Effect of the Escalator Dredge on Clam Bottom

Since the development of the escalator dredge there has been concern over the effects of the dredge on the clam resource, the bottom in the immediate area of dredging and adjacent bottom. Although this study did not address these questions, several other investigators have. For the convenience of the reader these papers are briefly reviewed here.

Kyte et. al. (1975) working in Maine reported that in the upper 4 cm stratum the number of juvenile clams was determined before and after dredging. No great change was observed at the first sampling after harvesting, but for subsequent samplings the trenched area yielded a greater density of juveniles than the surrounding flats. Manning (1957) working in Chesapeake Bay reported that in a 1 knot current or less, damage to adjacent oyster areas would likely occur out to a maximum of 75 feet. As to the trenching effect on the bottom, on the day of dredging the remaining trench was 2 inches to 8 inches deep (average 5 inches); after 4 to 6 days trench depth was 1 inch to 8 inches (average 3 inches) (Manning, 1957). In an area of repeated

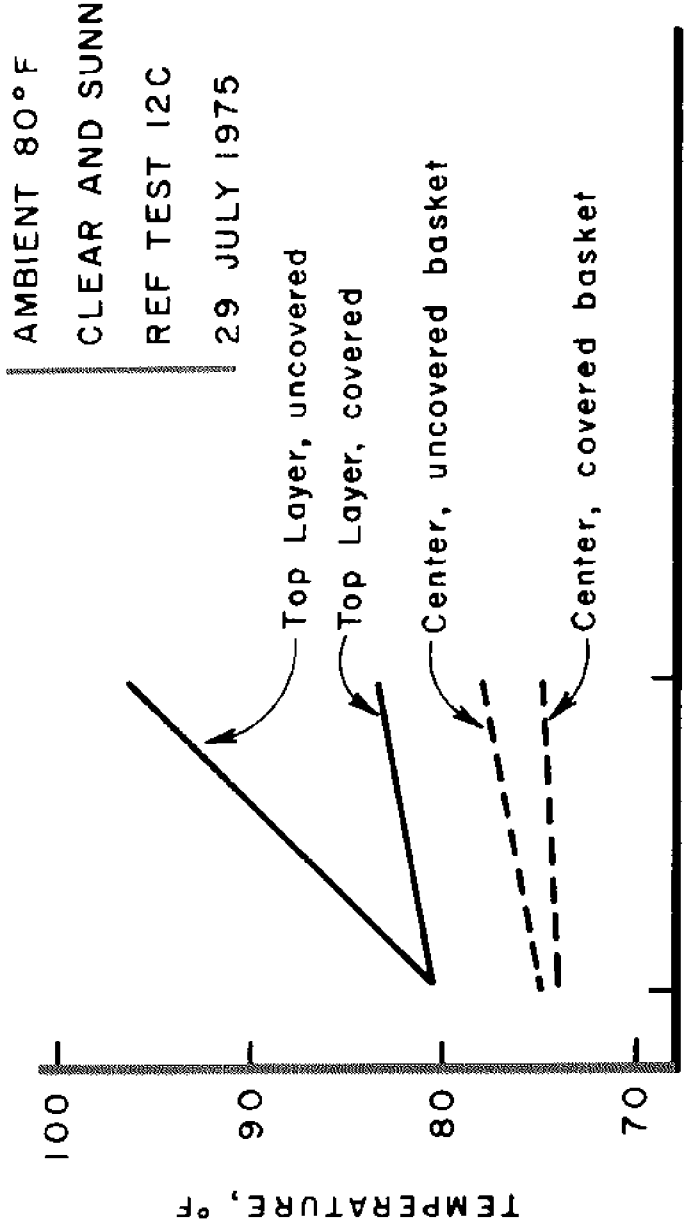

FIG. 81 Effect of shading by an empty inverted basket in reducing temperature increase of a bushel of clams exposed to direct sunlight.

commerical harvesting aquatic vegetation was essentially 100 percent removed. Pfitzenmeyer (1972) concluded from a series of dredging studies that the dredge can be used without seriously affecting the resource due to the good reproductive ability, rapid growth rate and reburrowing ability of clams in Chesapeake Bay.

The Clam Bushel

The bushel is the unit used to measure the volume of clams for harvest limits, taxes, yields and export quantities. It is the basic container size and the basis by which clams are bought and sold. Bushel weight and displacement volume were measured by Tatro, et. al. (1967). Four hundred and fifty bushels had a mean net weight of 67 pounds and a range of 62 to 72 pounds with a few as low as 55 pounds. The mean displacement volume was found to be 6.5 gallons with a range of 6.0 to 6.9 gallons.

This author weighed several baskets delivered to a processing plant. Net weights at the several plants were 6 at 56.7 pounds, 3 at 55 pounds, one at 60 pounds and one at 68 pounds for an average of 57.6 lbs. per basket. Much variation seems to exist, since there is no standard bushel weight.

Observations, Comments and Suggestions Relative to Dredging.

Some dredge conveyors are constructed with a slight arch (i.e., the middle of the conveyor frame is higher than at the ends). It appears that a conveyor with a slight catenary sag would reduce power requirements as the tension on the belt would tend to lift the belt off of the slides reducing drag friction.

Operation of the dredge in rough water is difficult in that boat pitch causes the dredge scoop to be raised and lowered. There is some point in the boat that is subject to minimum vertical movement. Locating the scoop support at that position, if possible, should reduce the effect of pitch on the vertical stability of the scoop.

It is also possible to develop a device to maintain the dredge head at the same level even though the boat is pitching. Before such a

device is developed, the economics of using it and the actual need for it should be assessed more thoroughly.

Propeller thrust during dredging is required to push the boat as well as force the dredge through the bottom. Since the scoop is offset to the right from the center of the boat, the center of resistance to forward travel is on a line from the propeller to slightly left of the scoop. A left rudder setting must be used continuously to counteract the offset loading. Power is wasted in proportion to the sine of the rudder angle. It is suggested that an inboard-outboard propeller system would put 100% of propeller thrust in the desired direction with no power loss at the rudder. The economics of this system need study before it is instituted.

The resultant force of the propeller, relative to the axis of the boat, is to the rear and to the left during dredging. The equal and opposite force on the boat-dredge system is therefore forward and towards the right. The keel of the boat serves to keep it moving in a direction parallel to the axis of the boat. However, at .3 mph the keel will not be too effective and it is suggested that the boat experiences significant slip to the right. If this is in fact the situation, then the scoop of the dredge is being pushed to the right as well as forward. A determination of the slip angle and the angular difference between the dredge axis and boat axis would provide the angle at which the scoop should be set relative to the conveyor. The elimination of side forces on the dredge would reduce thrust requirements necessary to push the dredge through the bottom. Further study of this situation would also be beneficial.

Most clam dredging rigs utilize two large internal combustion engines: one located amidship to turn the screw, a second on the left side to power the water pump and hydraulics as well as to offset the weight of the dredge. During travel to and from the harvest area the push motor is used at full power while the pump motor is not run. During dredging, the push motor runs at perhaps 1/4 power while the pump motor runs at full power. It is suggested that a single engine located on the left side of the boat could serve as a counterbalance and replace the two engines currently used. This single motor could

drive a hydraulic pump to provide power for the propeller drive, conveyors and hoists. Connection to the large dredging pump could be mechanical through a clutch.

Using this sytem, the demand of water pressure will dictate the speed of the engine during dredging. Hydraulic controls could adjust the power delivered to the propeller. The above equipment would not preclude the use of an inboard-outboard propeller arrangement or variable pitch propeller. Advantages of the single engine power source would be in reduced engine maintenance and operating costs, and additional deck space in the middle of the boat. Total dead load would be reduced. First cost of the above system may be somewhat higher than the present system but has not been established.

Relationship of Waterman to Clam Buyer

Boat and dredge usually are privately owned by the waterman, who often harvests on a contract basis for a processor, reshipper, or local steamer market. He usually knows beforehand how many bushels of clams he can sell on a particular day as well as the price. The waterman regularly sells to the same market at prices set by the buyers. Prices are most always in whole dollars per bushel delivered to the dock, processing plant or processor's collection point. The processor who empties baskets for his operation washes them and returns them to the waterman for his next day's catch. Clam shellstock shipped out of state must be in new wooden baskets or acceptable containers capable of being cleaned. The reshipper supplies the waterman with new baskets.

Transport of Soft Shell Clams

Once the clams reach the dock there are several alternative pathways they may follow. Fig. 82 indicates the clams may go directly to a party boat or bait supplier for sport fishermen, to a reshipper's cooler, directly to a restaurant or to a clam shucking plant. Any of these alternatives, with the possible exception of the party boat and a few processing plants, require transportation by truck.

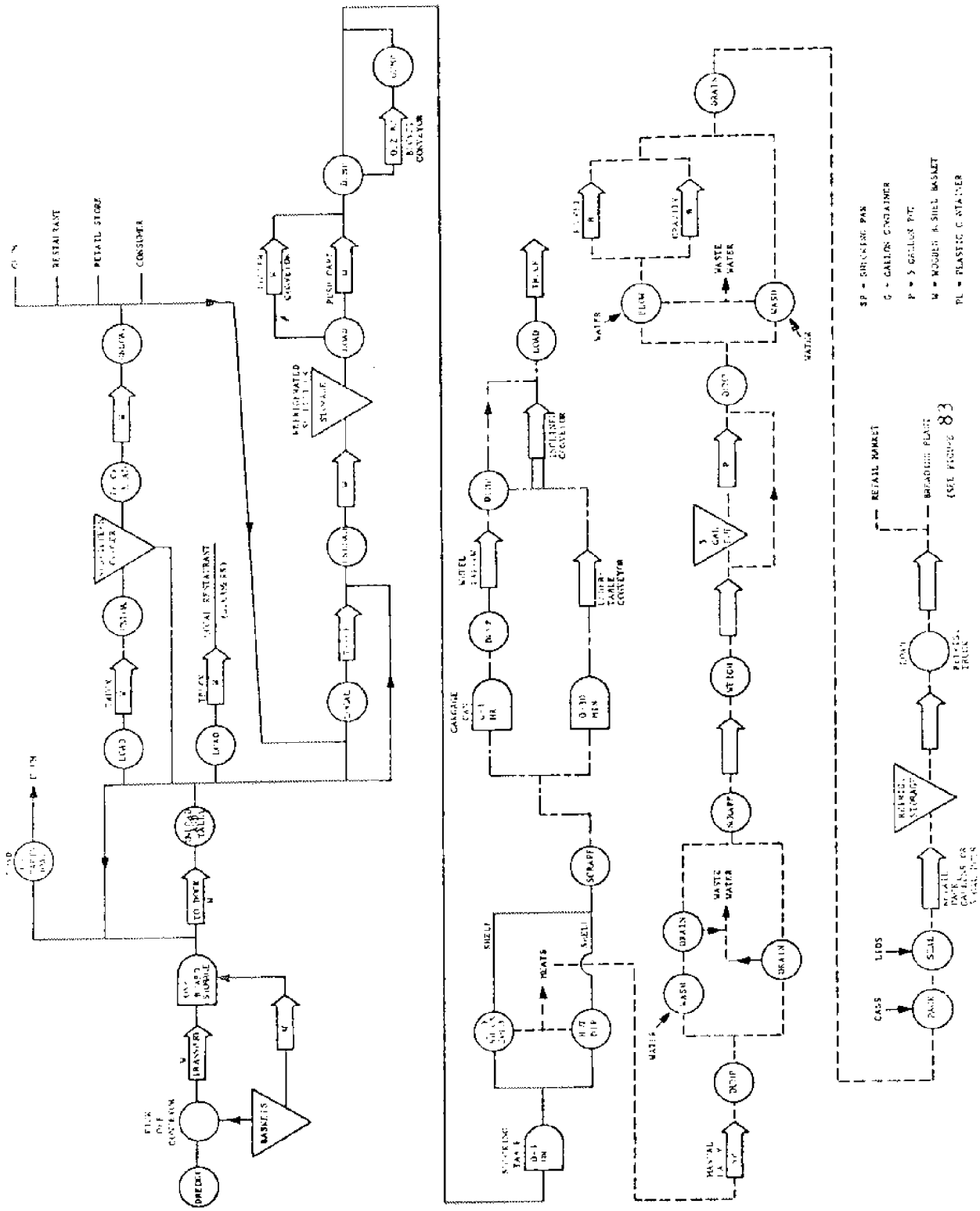

FIG. 82 Flow process diagram for the Maryland soft-shell clam industry.

The type of truck used in transport of clams depends to some degree on the distance they are hauled. Transport from dock to local destinations (e.g., up to 100 miles) usually is done on a small freight truck with a closed in box or on a pickup. Shading must be provided. However, care should be taken in design of the shading device. Placing a canvas or similar material directly on the clam baskets provides shade but drastically limits air circulation around the containers. This can lead to temperatures as high or higher than occurs in clams exposed to direct sunlight. In closed in trucks with no air circulation similar problems can occur.

Clams destined for transport directly to more distant points (e.g., New England) are generally placed in refrigerated trucks. Many refrigerated trucks are designed to hold a cold or cool product at 35 to 40°F but have insufficient refrigeration capacity or air circulation capacity to pull a warm product down to 35 to 40°F when placed in the truck. Warm clams directly from the dock should never be placed in this type of truck without precooling.

Generally, clams are shipped in the basket into which they were placed at harvest. However, a few processors and/or shippers use cleanable plastic containers. In loading trucks wooden baskets are placed in a row across the truck, a wooden rack placed across the baskets with the next layer placed on the racks. The racks transmit the weight of the above baskets to the edges of the supporting baskets. Some clams above the edge of the support basket are crushed in the process. While the baskets are new and clean, the racks or boards are not, and the possibility exists that drip water from the top layers can wash contaminants from the racks into the lower baskets. This is a potential site for bacterial contamination and care must be exercised to prevent it.

Much manual labor is used in the handling of shellstock. Baskets to be moved horizontally over a flat surface are often dragged with a 2 foot long hook. Vertical lifting of 4 feet or more is usually done by two persons. Movement of a large number of baskets from a cooler to a truck may be aided by the use of an inclined roller conveyor. Rough handling of clam baskets can cause significant breakage of clams. This increases the risk of high bacterial growth rates in these clams.

One reshipper collected and stored clams from a number of harvesters. On shipping days the harvesters unloaded their catch, docked their boats, then helped in the truck loading operation. On one observation a total of 268 bushels were loaded from three storage locations in 46 minutes by at times 13 men.

The plastic containers used for shipment of shellstock out of state are designed to nest when empty, but when rotated 180 degrees (end for end) and filled, the upper container rests in support notches in the container below it to prevent crushing of clams. No slats between layers of baskets are needed. Wooden bushel baskets are dumped into the plastic containers in the truck. The extent of breakage of shells as a result of dumping is not known.

Processing of Soft-Shell Clams

Fig. 82 shows a flow process diagram for the entire soft shell clam industry except for the frozen breaded operation. The flow process diagram for the process producing frozen breaded soft shell clams is shown in Fig. 83. These flow process diagrams detail each step through which the clams must pass from harvest to final market. The various symbols utilized follow standard industrial engineering notation in which an inverted triangle designates a storage, an arrow designates a transportation operation, a circle designates a process, a square an inspection and a combination of a square and a semicircle (an elongated "D" shape) designates a delay in the flow of materials. Although the processing of soft shell clams is a relatively simple process many operations are involved. Manual labor predominates primarily due to limited volume processed in each plant and a lack of any automated means of shucking clams.

Clams are predominantly utilized in one of four ways: frozen breaded, fresh shucked, fresh in the shell for steaming (steamers) or fresh in the shell for chum(fish bait). Frozen breaded clams are usually produced in a separate processing facility where chilled fresh shucked clams are the raw material. Fresh shucked clams are produced by a hand shucking operation. Their final destination is generally

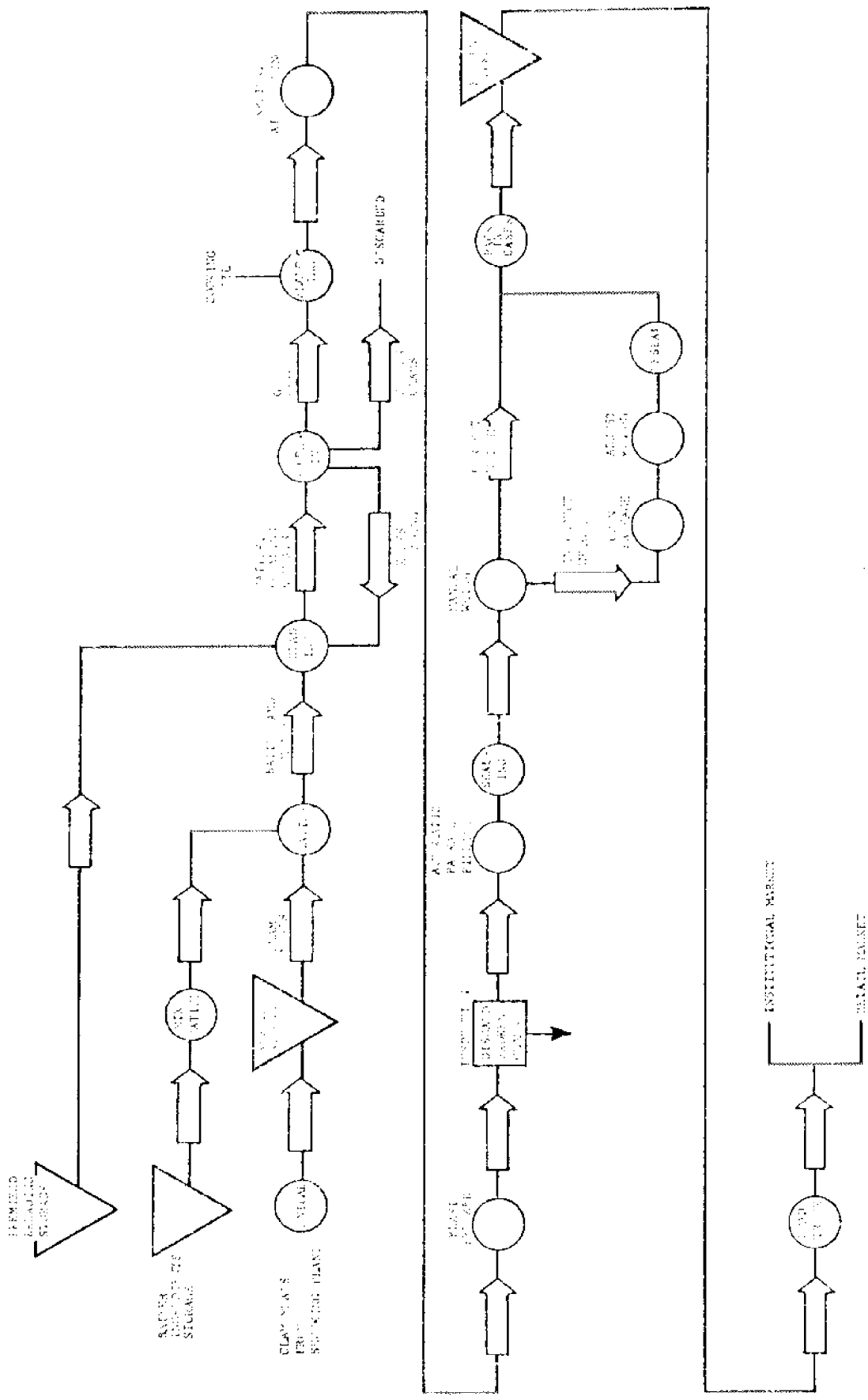

FIG. 83 Flow process diagram for producing frozen breaded soft-shell clams.

either a breading plant or an institutional market such as a restaurant. Steamers generally are retailed or go to restaurants. Soft shell clams make excellent chumming bait for rock bass or blue fish. Thus, considerable quantities of clams are sold to party boat captains and fishermen which are then ground up and used as chum bait.

The volume of clams going to the various markets is not generally broken out in statistical data for Maryland although it probably can be determined for the processed products. Little if any hard data is available on the volume of soft shell calms used for bait. The proportion of harvested clams going to the several uses obviously varies with season, availability of clams and price.

Soft Clam Shucking Operations

Shucking plant facilities may be located either inland or on an estuary. The plant usually consists of masonry block construction on a concrete slab, with a truss roof. Each plant has its own well (unless city water is available) and ice making facilities. Some have indoor flush toilets while others have outside privies. In addition to shucking soft shell clams, the plant facility may also be used for picking crabs and/or shucking oysters. Oysters and clams may be packed in the same area in the plant if separate equipment is used. Employment for processing clams in the plants visited ranged from 15 to 45. However, some plants could employ up to 70 persons during periods of good clam availability, good consumer demand and ready availability of labor.

Soft shell clam shucking plants in Maryland each have a unique layout. However, they generally are divided into several areas. Generally, these areas are: receiving, shipping, shell stock storage (refrigerated), shucking, packing and shucked product storage. In addition, ice making facilities, restrooms and washup areas for employees, office facilities and in some cases waste disposal systems for the plant effluent are also present.

Receiving and Shipping

Clams in bushel baskets are delivered to the plant by the waterman. Most delivery is by pickup truck, Fig. 84. A smaller number are moved directly from the boat to those plants having docking facilities and are near a clam harvest site. Some processors send a covered truck to a dock to collect clams from several watermen. The loading platforms of plants vary in height from ground level to the level of a pickup truck bed. Delivered clams go to one of two places: the walk-in refrigerator (Fig. 85) or to a larger refrigerated truck for out of state export.

The floor of the cooler is usually at the same level as the loading platform. Methods of moving baskets include: direct carry by one or two men, dragging on the ground with a hooked rod, a two wheel push truck moving one bushel per trip, a wheelbarrow with modified platform capable of hauling 2 baskets, a 4-wheel push cart of various sizes capable of hauling 3 to 15 bushels depending on area and number of layers, and an inclined roller conveyor. Watermen provide much of the labor for moving clams into refrigeration or secondary transportation.

The time required to unload and move baskets into storage by two means was measured. In the first case, baskets were manually lowered to a low-level dock from the truck, dragged 20 feet to the cooler of Fig. 85, then lifted by two men into place. The number of men working at any one time varied between 2 and 5. Unloading of 3 loads of 15 bushels each required an average of 3.6 minutes per load, and utilized an average of 3.7 men or 13 man-minutes. At a second plant, a 4-wheel push cart was used to move 7 or 8 bushels 40 ft. to the cooler. One man, working alone was able to unload and store 15 bushels in 6 minutes.

No observations were made of any shellstock being weighed at time of delivery. The plant supplied the waterman with empty baskets for his next day's catch.

An analysis of the material handling requirements of one plant was conducted relative to the feasibility of switching to a palletized system. It was determined that palletizing was not economically

FIG. 84 Method by which most clams are delivered to shucking plants.

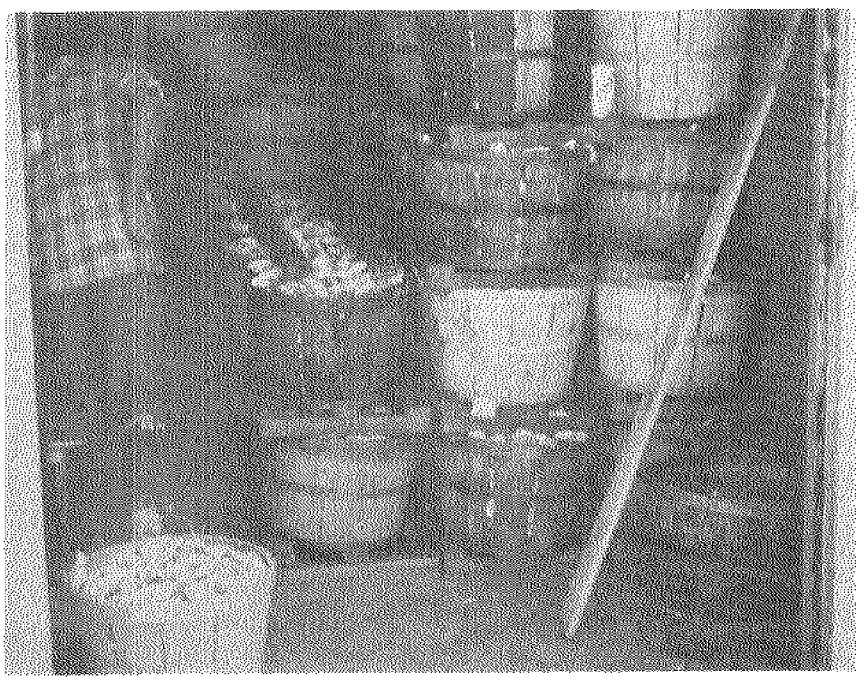

FIG. 85 Method of storage of clam shellstock in walk-in coolers.

justified due to the limited amount of labor saved for each operation, the nature of the products handled, and the relatively small quantity of materials being moved.

Refrigerated Storage

Shellstock is placed under refrigeration immediately upon delivery to the plant. Clams are kept in the container they were delivered in and are not washed. Shellfish regulations (Salinger, 1970) require that shellstock be cooled to 50°F within 7 hours and 40°F within 12 hours. The pulldown rates for two baskets in a small cooler are presented in Fig. 86. Eleven hours were required to cool one basket from 69°F to 50°F.

A single basket of clams was warmed to 81°F then placed in a conventional household type refrigerator to cool. The refrigerator had a 5 in. circulating fan as part of its original equipment. Fig. 87 shows the rate of cooling at the center of the basket and the internal refrigerator air temperature. Thirteen hours were required to cool the clams to 50°F with a minimum refrigerator temperature of 42°F.

Further cooling rates were observed during the on-board bacterial studies. For these tests two containers of clams, a warm wooden basket and a previously cooled full flow container, were placed in the refrigerator. For 12 appropriate tests the average initial temperature of the warm basket was 72°F. The average time required to cool the center of the basket to 50°F was 14 hours. Refrigerator temperature after initial cooling was approximately 40°F.

The cooling rates in the above tests are felt to be similar to those achievable in walk-in coolers. Both have conditions of minimal air circulation through the basket and air temperatures of 35 to 40°F. Icing of the refrigerator evaporator coil will occur if too low an air temperature is attempted. Cooling time to 40°F is not presented as they were extremely variable and dependent on refrigerator air temperature. Previous bacteria growth rate studies (Section III) demonstrated a fairly consistent stabilization of bacterial levels at 50°F. The primary aim of a shellstock cooler, then, should be to rapidly

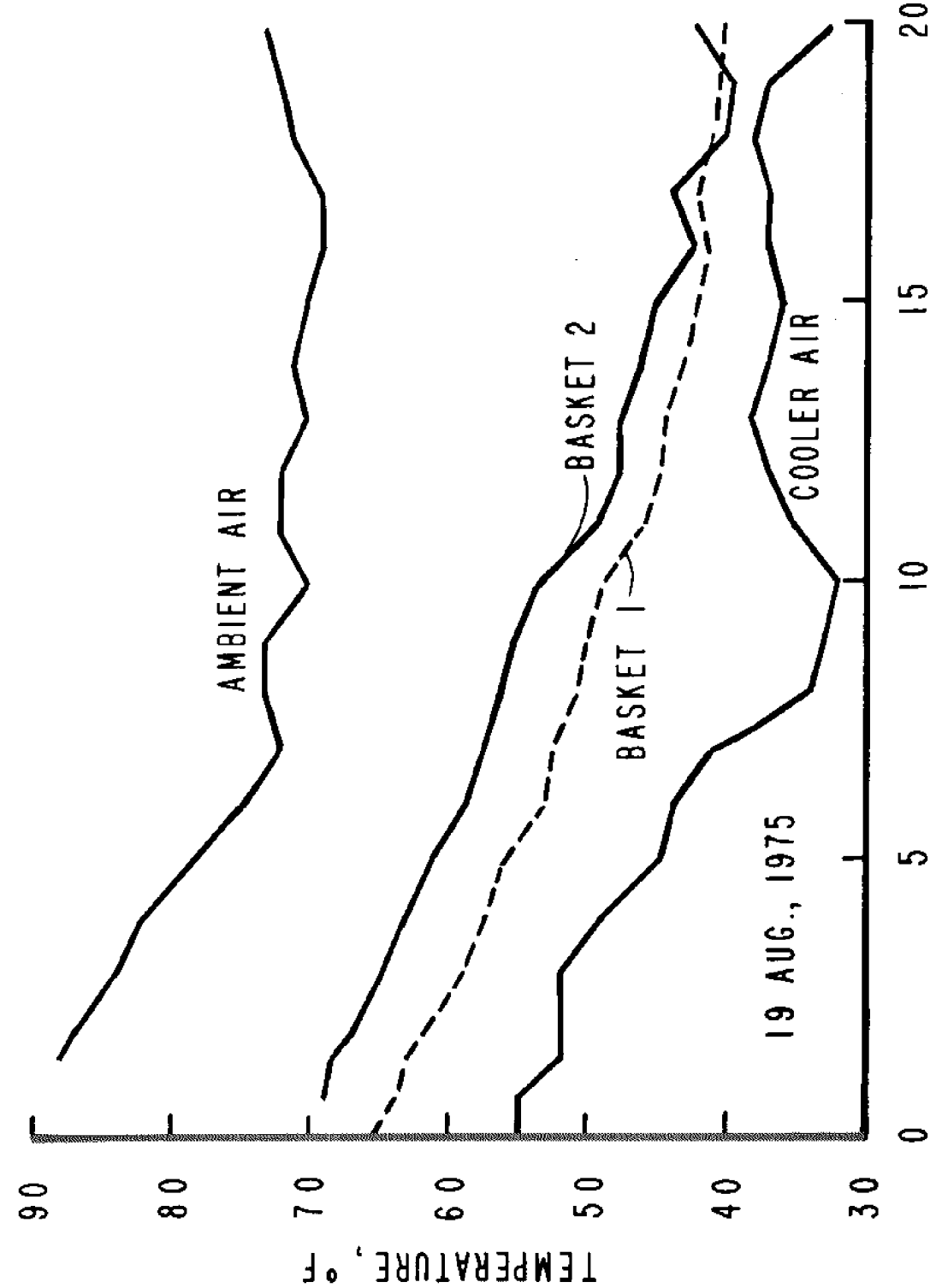

FIG. 86 Cooling rate for two bushels of clams placed in a small walk-in cooler.

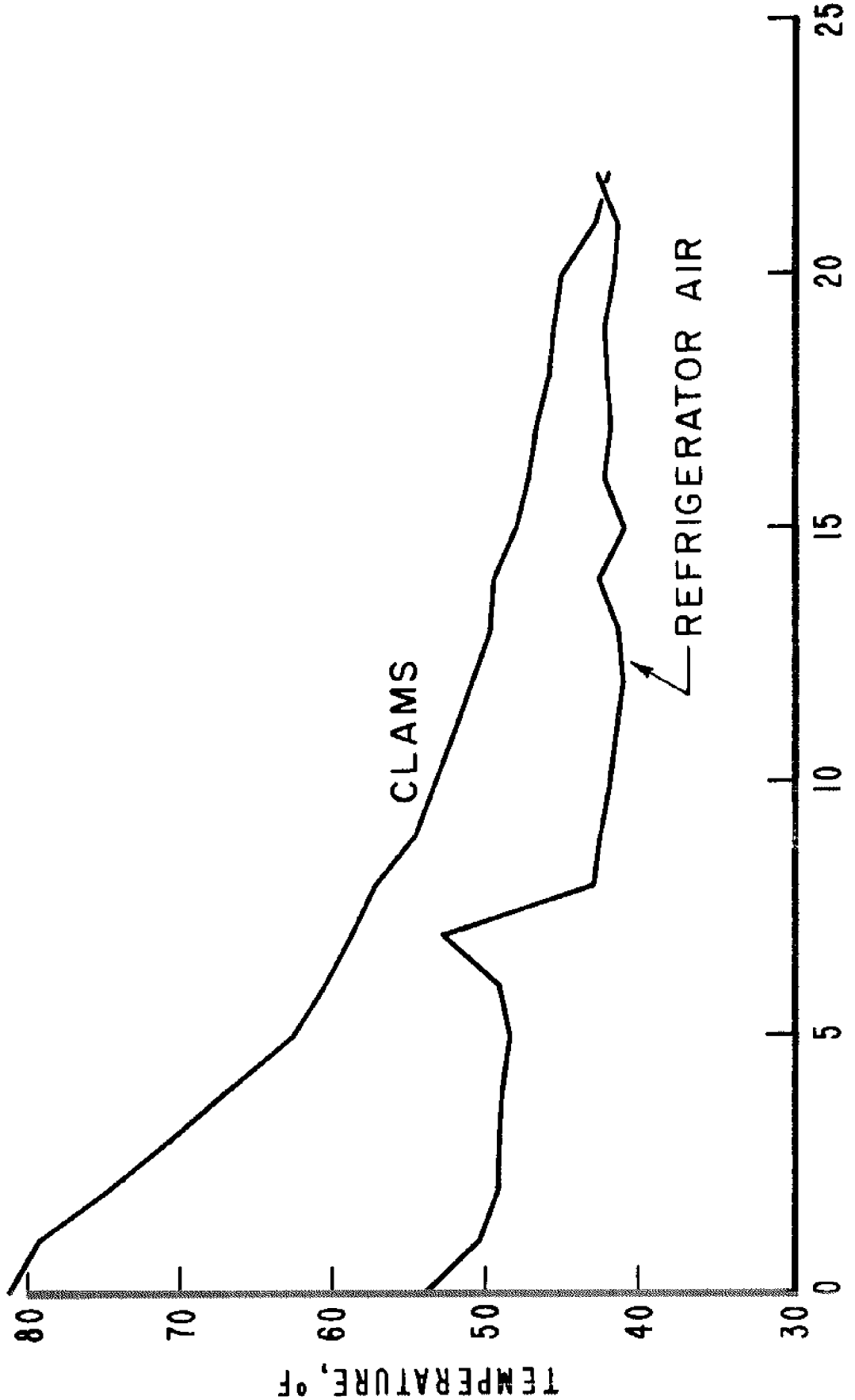

FIG. 87 Measured cooling rate for a single wooden bushel basket of clams in a household type refrigerator. A five inch circulating fan was part of the refrigeration system.

reduce shellstock temperature to less than 50°F. Further reduction to lower temperatures need not be as rapid.

In the plants studied, those coolers used strictly for shellstock storage ranged in size from 180 to 280 square feet. One much larger cooler was used for storage of clam meats and flaked ice in addition to shellstock. Baskets are stored in straight rows of 5 to 6 baskets. A row of 5 requires a floor area of 90 x 18 inches. Usual depth is 4 layers, having a top height of 55 inches, but can be as high as 6 layers. Preconstructed racks or individual strips of wood are used to separate layers of baskets and to transfer the weight of an upper layer to the edges of the supporting basket and not to the clams. Some clams extending above the edge of the lower baskets were broken during placement of the racks. No sterilizing of the racks was observed, nor were provisions for this process apparent.

The refrigeration unit for the smaller coolers was usually of the 3 hp size. Larger coolers used multiple units.

Most of the shucking plants had a separate cooler for storage of the shucked meats. An ice machine was situated above the cooler with ice output allowed to fall by gravity to a floor level bin within the cooler. Ice was used to cool containers of meats within the cooler. Ice was also used during the blowing process to reduce meat temperature. The exposed ground level storage of ice and its handling with conventional shovels and wheelbarrows often created opportunities for direct bacterial contamination of the meats.

Shucking

Separation of the clam meats from the shell and siphon is entirely manual. Dipping the clams in 180°F water for a short period of time to make removal of the shells easier and to possibly reduce bacterial levels is an infrequently used shucking aid. This hot dip method was not used in any of the studied plants and is not reviewed here.

The vast majority of shuckers are female, of all ages. Transportation to and from the plant will frequently be supplied to the shuckers in the form of a bus or plant-owned car on loan.

A separate room of the plant is devoted to shucking. Work is performed at tables of various sizes and descriptions, all having a top surface of stainless steel. Depending on table height and preference, the shucker will sit on either a chair or stool or will stand on the floor or an elevated wooden runner board. Equipment required is minimal and includes a shucking knife which is owned and retained by the shucker, a two quart stainless steel shucking pan into which shucked meats are placed, and a rubber or plastic apron. Figs. 88 and 89 are examples of shucking knives used in Maryland.

Shellstock in wooden baskets is transported to the shucking area by means as diverse as manually carrying a single basket or through use of a push cart holding six bushels. Clams are dumped in a pile on the table surface within reach of one or more shuckers either directly from the basket or from a conveyor system filled at a central point. An extra partial dumping into a second basket is used to fill the conveyor buckets. The second basket is then dumped into the nearest empty conveyor bucket.

The time required to take an empty push cart into the cooler, load 6 bushels and return to the shucking room was 1 minute 15 seconds. Total time to dump all 6 bushels into empty conveyor buckets was estimated at 10 minutes.

The shucking procedure (Figs. 90 through 97) for a right handed shucker starts when a clam is removed from the pile with the left hand. It is held firmly between the thumb and first 3 fingers with the hinge to the left and the siphon pointing away from the shucker and slightly up (Fig. 90). The knife is inserted just under the top shell half between the shell and the siphon. A clockwise cut is made just under the shell edge and over the full perimeter of the top shell except through the hinge (Fig. 91). The top shell is pried off (Fig. 92) at the finish of the cut and allowed to drop to the table. A second cut along the top edge of the bottom shell will separate the shell from the meat and siphon (Figs. 93 and 94). As part of the separation, the posterior adductor muscle, to the left of the base of the siphon, might be torn using the left thumb. The lower shell is allowed to fall to the table, the left hand still holding the meat and siphon. The body portion of clam is supported in the palm of the hand (Fig. 95), while

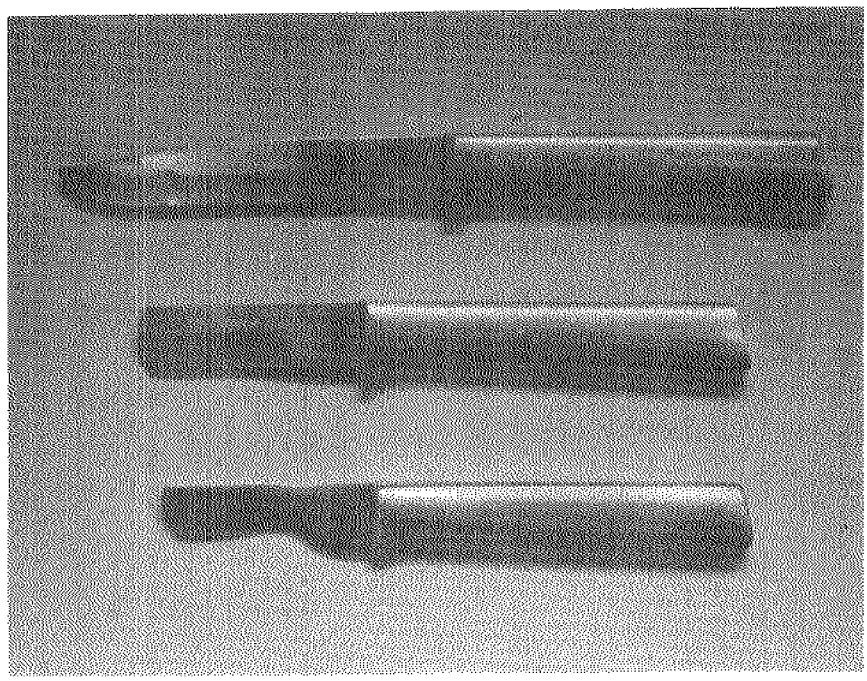

FIG. 88 Original paring knife (top) from which the lower two clam shucking knives were fashioned.

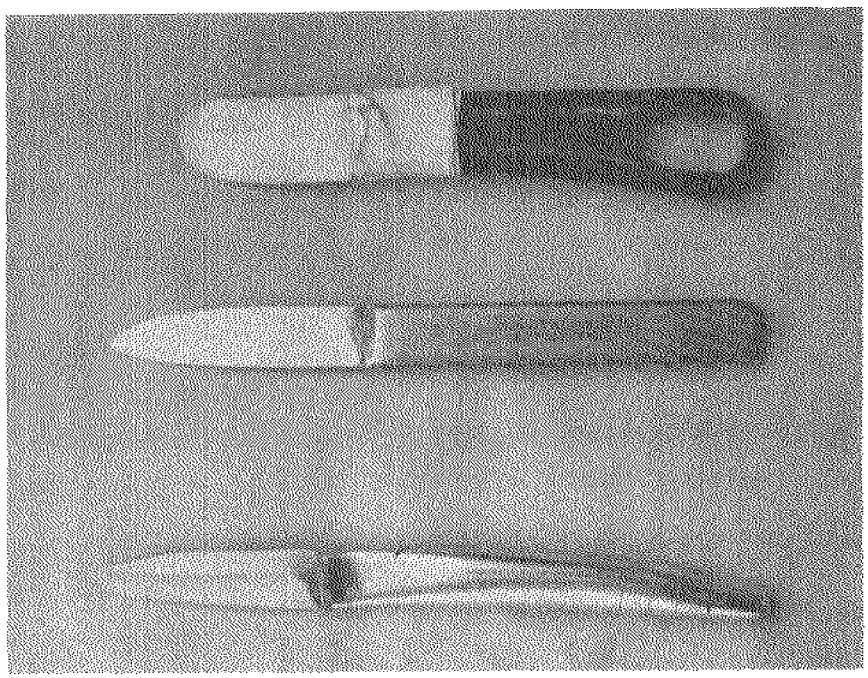

FIG. 89 Top: Shucking knife fashioned from Army messkit knife. Middle: All stainless steel knife manufactured expressly for clam shucking. Bottom: Knife of unknown origin.

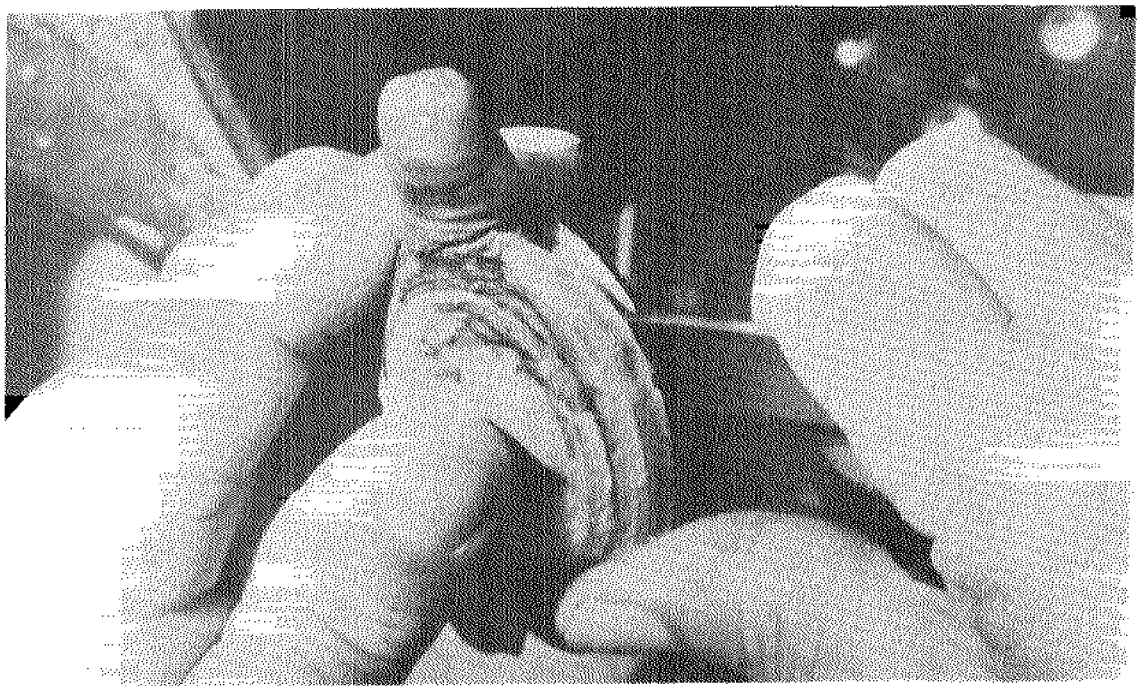

FIG. 90 Manual clam shucking: cutting top shell free.

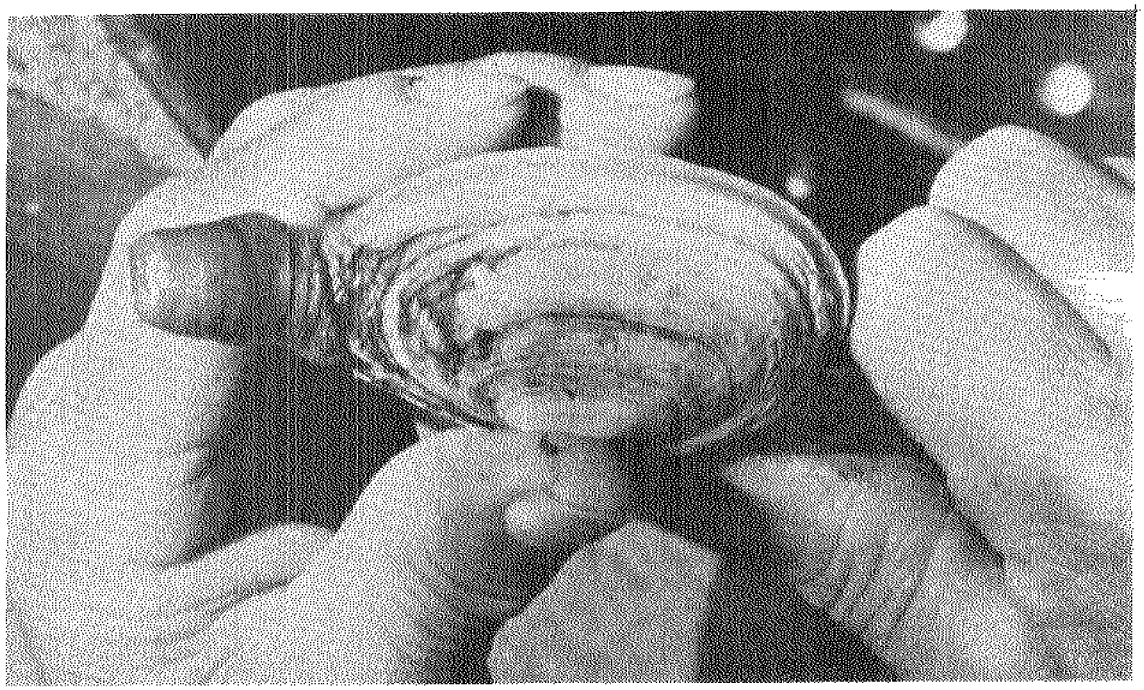

FIG. 91 Manual clam shucking: finishing first cut to free top shell.

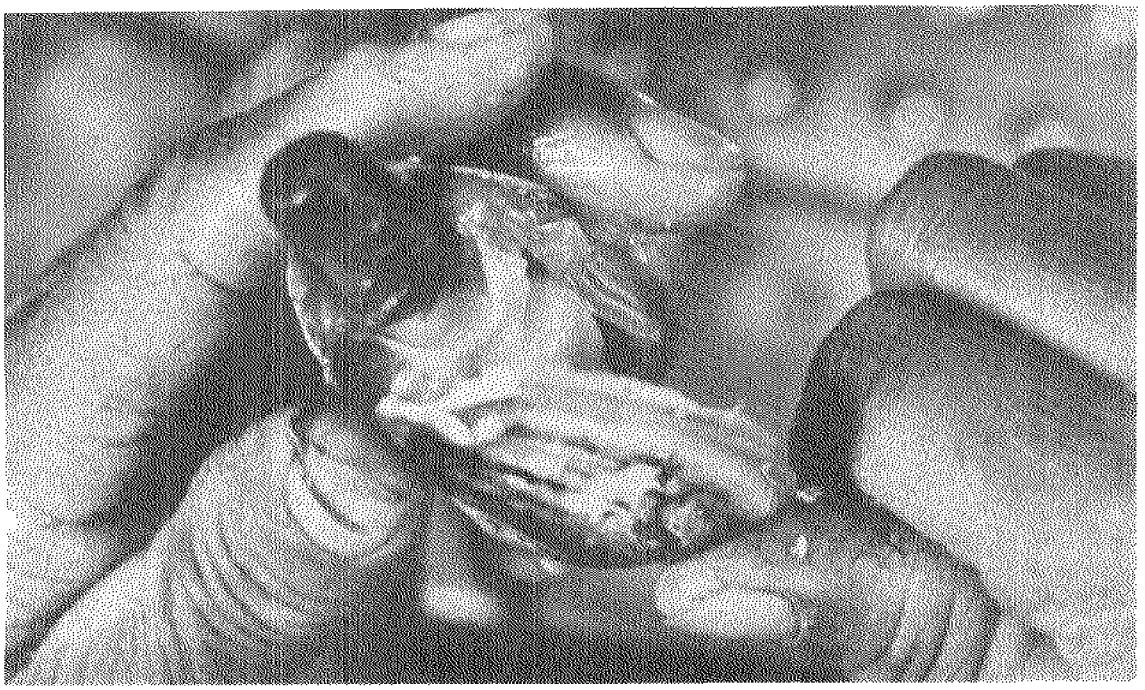

FIG. 92 Manual clam shucking: prying top shell off.

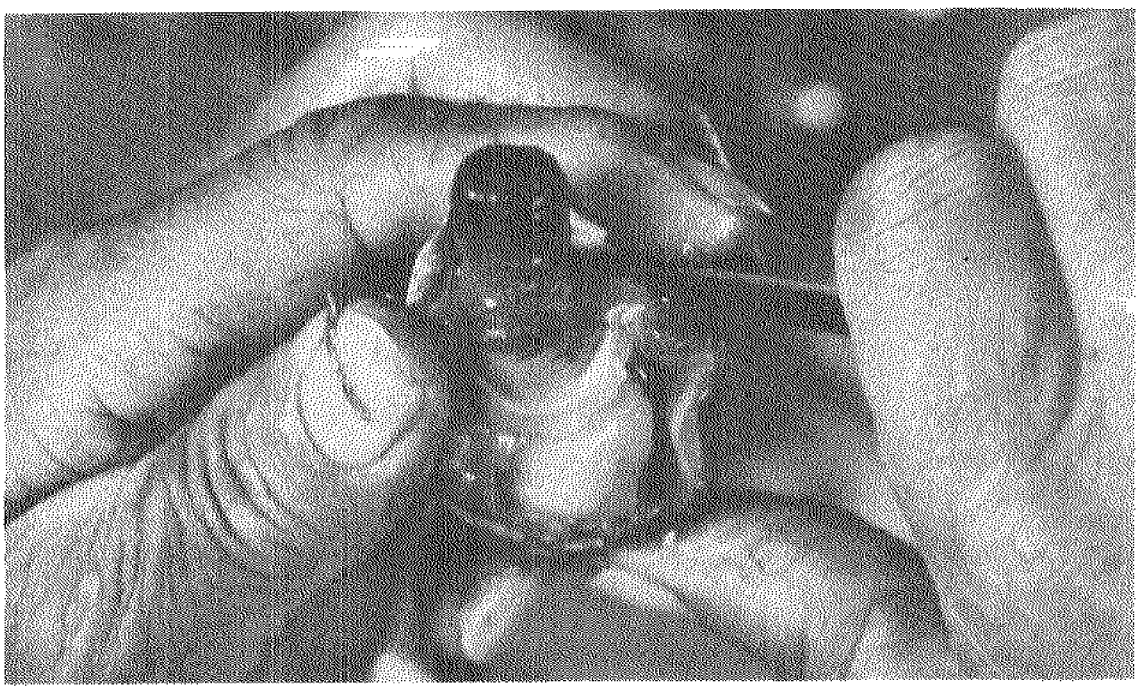

FIG. 93 Manual clam shucking: starting second cut.

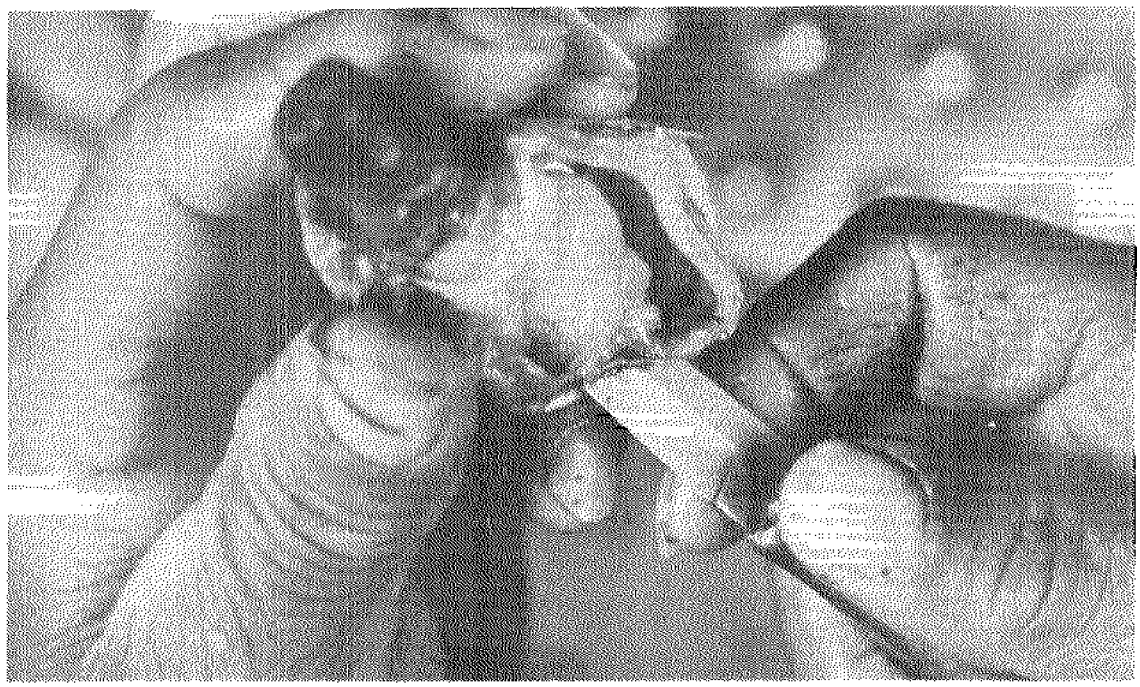

FIG. 94 Manual clam shucking: end of cut used to free bottom shell.

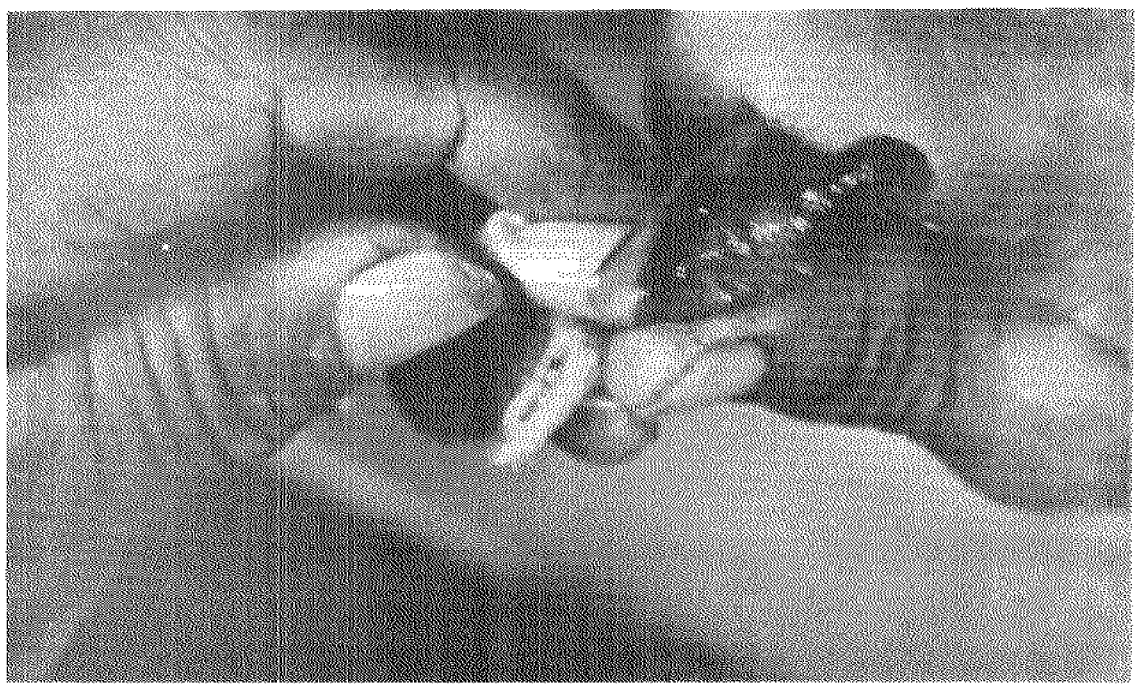

FIG. 95 Manual clam shucking: positioning for removing siphon.

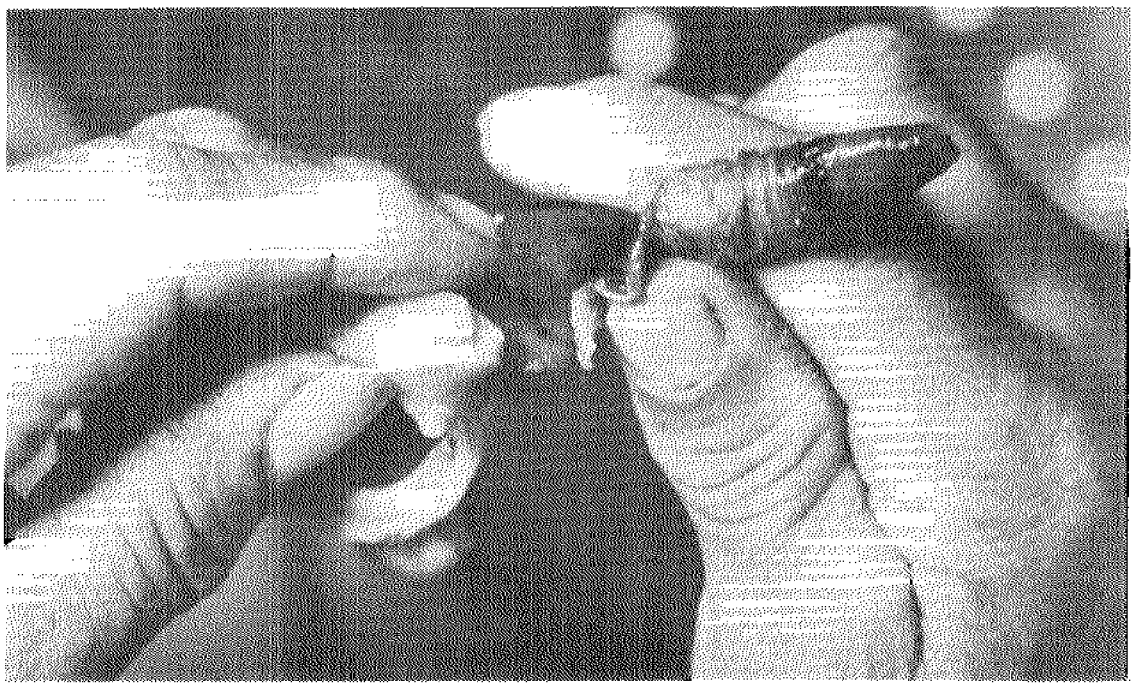

FIG. 96 Manual clam shucking: removing siphon.

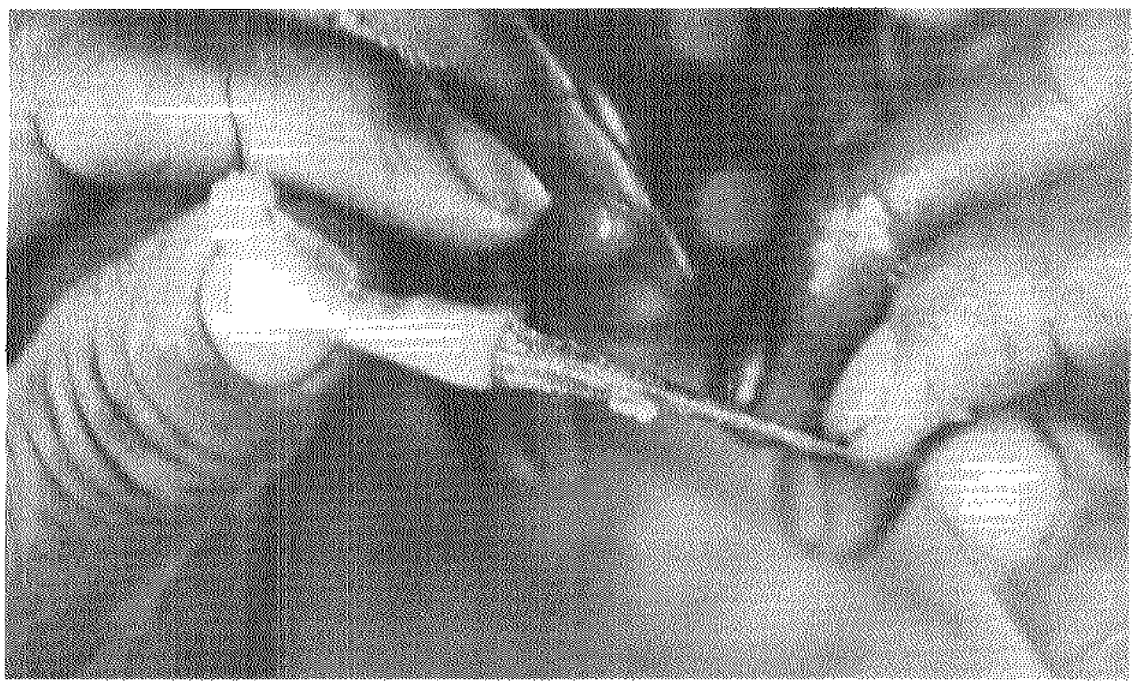

FIG. 97 Manual clam shucking: removing skin from meat.

the thumb and first two fingers hold the base of the siphon. The siphon is severed (Fig. 96) at a point about 3/8 inch from its inner end. This is done with the shucking knife cutting against the right thumb. The darker skin or outer membrane (Fig. 97) is removed after cutting off the siphon and dropped to the table with the shells. The clam meat is placed in the 2 quart shucking pan and another live clam retrieved from the pile. When a number of shells accumulated on the table, shucking was stopped and the shells pushed off the table edge into shell collection cans or was pushed into inclined chutes leading to a shell removal conveyor.

Correct and complete removal of the skin covering the siphon is important because during frying any remaining skin drops off and appears as a string in the product. Complete removal of the skin is facilitated by not cutting through the skin when removing the siphon during shucking. If the skin is not cut it can be peeled off cleanly.

A properly shucked clam forms a continuous ring. A ring is a more appealing product when fried than the long stringy shape resulting from improperly shucked clams. Fig. 98 shows various sizes of properly shucked, rinsed clam meats.

Normally, all internal clam organs are included in the meat. However, there is one exception to this. At certain times of the year and under certain environmental conditions in the Bay soft shell clams accumulate a red pigment which is not harmful to persons eating the clams. However, the red color appearing in the processed product gives the appearance of a bloody product and causes total rejection by the consumer (Beaver, 1964). Lear (1958) showed this pigment concentrated in the digestive glands of the soft shell clam. Thus, some clam processors remove the digestive glands during processing. This is termed "popping the clam." Some plants were observed to "pop clams" for a portion of their product as a customer service and at no additional cost to the customer. Shuckers were paid the same rate whether "popping" or not even though their shucking rate and the yield were decreased when "popping" was done. Further information on red coloration of clams can be found in Boon (1972) and Beaver (1964).

Shucking rates were observed and recorded in several plants. Measured quantities included the number of clams per minute and pounds

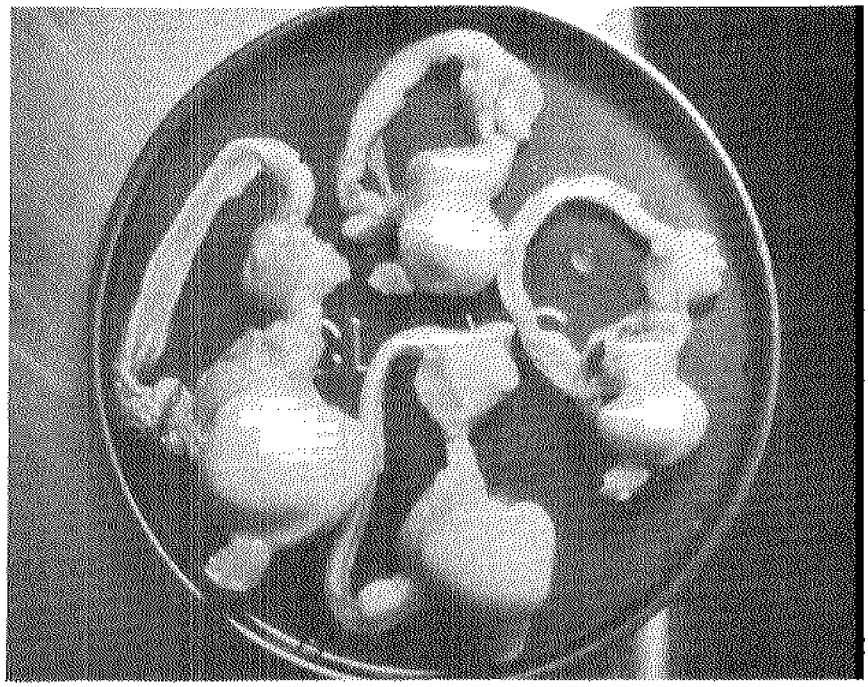

FIG. 98 **Freshly shucked and rinsed** clam meats of varies sizes.

per hour. The number of clams shucked per minute was determined by measuring the time to shuck a known number of clams, usually 20. All measurements were of continuous shucking. Table 30 summarizes the rates.

TABLE 30. OBSERVED NUMERICAL RATE OF SHUCKING BY TEN SHUCKERS WORKING CONTINUOUSLY THROUGHOUT THE PERIOD OF OBSERVATION

Shucker	No. clams shucked/time, min:sec			Total clams	Total time, min.	Clams per minute
1K	20/2:15	13/1:37	25/2:42	58	6.57	8.83
2K	20/2:17	20/2:40	20/2:57	60	7.90	7.59
3K	20/2:22	20/2:09	20/2:37	60	7.13	8.42
4K	20/2:10	20/2:30	20/2:16	60	6.93	8.66
5K	18/1:54	30/3:42		48	5.60	8.57
1L	20/3:26	20/3:49	20/3:13	60	10.47	5.73
2L	20/2:19	20/2:49	20/2:43	60	7.85	7.64
3L	20/3:01	20/2:32	20/2:32	60	8.08	7.43
4L	20/2:09	20/2:03	20/1:52	60	6.07	9.88
5L	20/2:05	20/2:09	20/2:07	60	6.35	9.45
F8K	20/2:09	20/2:14	20/2:15			
	20/2:21	20/2:24	20/2:04			
	20/2:21	20/2:26		160	18.23	8.77
F6K	20/2:03	20/2:08	20/2:07			
	20/2:03	20/2:35		100	10.93	9.15
					Average	8.34

An average shucking rate of 8.34 clams per minute with a standard deviation of 1.11 clams/min resulted from the above 42 observations of 12 shuckers. No measure of the quality and purity of the finished meats was available.

The quantity of meats produced per hour is another measure of shucking rate. The time interval required for a shucker to fill the 2 quart pan was determined. Net drained weight of the meats was obtained either by direct observation of the scale reading or by conversion from the shucker's payment knowing the payment rate per pound of meats. Table 31 provides the measured production rates of several shuckers from several plants.

TABLE 31. MEASURED PRODUCTION RATES OF INDIVIDUAL CLAM SHUCKERS. QUANTITY OF MEATS IS THE AMOUNT PLACED IN A STANDARD SHUCKING PAN

Shucker	Time per pan, hr	Meat weight per pan, lb.	Shucking Rate, lb/hr	Average Shucking Rate, lb/hr
	0.77	6.09	7.91	
1L	0.70	5.63	8.04	7.74
	0.78	5.66	7.26	
	0.55	5.89	10.71	
2L	0.53	5.89	11.11	10.50
	0.65	6.29	9.68	
	0.50	5.37	10.74	
3L	0.47	5.54	11.79	10.76
	0.58	5.66	9.76	
	0.47	6.29	13.38	
4L	0.42	6.37	15.17	14.75
	0.38	5.97	15.71	
	0.48	6.54	13.63	
5L	0.42	6.37	15.17	13.81
	0.48	6.06	12.63	
	0.55	6.29	11.44	
1S	0.43	5.71	13.28	12.18
	0.38	4.49	11.82	
2S	0.55	5.43	9.87	9.49
	0.62	5.65	9.11	
3S	0.52	5.31	10.21	10.49
	0.53	5.71	10.77	
4S	0.57	6.00	10.52	11.81
	0.45	5.89	13.09	
5S	0.48	6.00	12.50	12.76
	0.45	5.86	13.02	
	0.50	5.57	11.14	
6S	0.40	5.14	12.85	12.76
	0.28	4.00	14.29	
	0.52	5.71	10.98	
7S	0.43	5.66	13.16	12.05
	0.25	3.00	12.00	
	0.57	5.71	10.02	
8S	0.47	4.77	10.15	10.94
	0.35	4.43	12.66	

TABLE 31. CONTINUED

Shucker	Time per pan, hr	Meat weight per pan, lb.	Shucking Rate, lb/hr	Average Shucking Rate, lb/hr
9S	0.25	6.00	24.00	19.20
	0.30	5.71	19.03	
	0.33	5.71	17.30	
	0.37	5.71	15.40	
	0.28	5.71	20.39	
	0.13	2.48	19.08	
10S	0.62	6.00	9.68	11.50
	0.58	6.11	10.53	
	0.38	5.43	14.29	
11S	0.55	5.06	9.20	8.45
	0.78	6.00	7.69	
F8K	0.62	5.60	9.03	9.03
F6K	0.60	5.30	8.83	8.83
S2	0.65	8.14	12.52	12.52
S6	0.65	8.03	12.35	12.35
S9	0.65	9.20	14.15	14.15
S31	0.65	9.71	14.94	14.94
			Average for all shuckers	11.86
			Standard Deviation of all shuckers	2.59

The last four shuckers of Table 31 simultaneously shucked a discrete two bushels. Yield per bushel was 17.54 lbs. of meat.

A test was conducted to determine the effect of clam size on the shucking rate (clams per minute) and on production rate (lbs meats per hour). One bushel was sorted, starting from a full basket, by separating 100 large (2 1/2 inches and over) and 100 smalls (2 1/4 to 2 1/2 inches) in separate baskets. (At this time the legal minimum length was 2 1/4 inches.) All broken and cracked clams were discarded. Net weight of each group was determined to the nearest 1/4 pound. One shucker worked steadily to shuck first the small group, then the large group. The time and drained clam weight was recorded. Table 32 presents the results.

TABLE 32. COMPARATIVE SHUCKING AND PRODUCTION RATES FOR TWO SIZES OF CLAMS.

Shucker	Clam Size	No. Clams	Live Weight, lb	Shucking time, min	Meat weight, lb	Shucking rate, clams per min	Production rate, lb per hr
D4	small	100	5.5	15.0	1.4	6.67	5.6
	large	100	7.75	16.2	2.2	6.17	8.14
D2	small	100	5.5	11.9	1.4	8.43	7.08
	large	100	8.0	10.8	2.1	9.27	11.69

The results indicate that the shucking rate (clams per min.) was essentially the same for the two sizes but that production rate (lb per hr) increased with the larger clams.

An estimate of the theoretical yield per bushel can be derived from the above data. For the D4 test the size ratio for the total container was 136 smalls to 100 large. Since the 100 smalls weighed 5.5 lb, 136 smalls would weigh 7.48 lb and yield 1.90 lb meats. Combining both sizes, the total weight for 236 clams would be

7.48 + 7.75 = 15.23 pounds of shellstock yielding 1.9 + 2.2 = 4.1 lb meats. A bushel containing 56 pounds would yield (56/15.23)(4.1) = 15.1 pounds of meats. A theoretical 867 clams per bushel is calculated.

For the D2 test and a different bushel supply, the ratio of smalls to large was one to one. Extrapolated yield for a 56 lb bushel is (56/(5.5 + 8.0)) (1.4 + 2.1) = 16.9 lb meats per bushel. A theoretical 829 clams per bushel is calculated.

In practice the yield per bushel will be reduced by the number of broken clams not chucked, small clams that are deliberately thrown away and any clams that accidentally end up in the shell pile and are discarded. By actual count one bushel contained 126 broken clams out of 871 total or a broken rate of 14%. Small breaks in the shell near to and parallel to the edge of the shell were not counted as broken but would still hinder the shucking operation.

An estimate of overall production rate is obtained from a plant where 26 shuckers were shucking at the rate of 12 bushels per hour or 0.46 bushels per shucker per hour.

Using the data from Table 32 and the calculation given immediately below these tables it is possible to calculate an average shucking rate for shuckers in terms of bushels per shucker per hour. For the two 56 lb bushels of clams there was a yield of 15.1 pounds and 16.9 pounds of clam meats per bushel, respectively. This averages to 16.0 lb meats per bushel of clams. Table 31 gives an average shucking rate for the shuckers timed of 11.86 lb of meat per hour. Therefore, an average shucker is shucking about (11.86 lb/hr) ÷ 16.0 lb/bu or 0.74 bushels of clams per hour per shucker. This rate is almost double the actual output (0.46 bushels/shucker/hour) noted above for a total plant having 26 shuckers. The difference in these two values is due to several factors. First, the 0.74 value does not include personal time (time to go to the restroom, have a smoke, etc.) or fatigue time (time required due to humans getting tired as they work for longer periods). Generally, industrial allowances for fatigue and personal time are about 20 percent of the total time. Using a 20% allowance the 0.74 bu/shucker/hr becomes 0.59 bu/shucker/hr. Although the

0.46 bu/shucker/hr and 0.59 bu/shucker/hr are still significantly different, the difference could easily be due to management and/or employee practices in one or more of the plants. Thus, an average shucker will normally shuck between 0.50 and 0.60 bu/hr of soft shell clams when the rate is calculated over a daily or longer time period. Where in this range a total plant will fall will depend on experience, management expertise, and shucker attitude.

Possible Problems During Shucking

Several practices were observed that would potentially allow the shucking operation to contribute to bacterial contamination of the meats. Shellstock is placed in a pile in the center of the table at the start of shucking. To maintain a continuous operation additional clams are frequently added to the pile thus providing for the possibility of some clams being on the table for the full day. In one instance a shucker was observed to open a dead clam. The smell alerted the shucker and it was discarded. Fluids dripping from the clam contaminated the table and the knife, neither of which were washed before the next clam was shucked. One shucker had a habit of hooking clams over a finger of the hand used to hold the clam during shucking. These meats were dragged over the shell pile and table surface during the process. Some shuckers try to put too many meats into the 2 quart pan. Many then fall to the table and must be put back into the pan. In addition to contamination possibilities, the shucker wasted time with the additional step. Shuckers were observed using coffee cups for clam meat retention. Some of the shuckers who overfilled the pan carried the pan up against their apron to reduce the chance for meats to fall off. In those plants using garbage cans for temporary tableside storage of snouts and shells, the shucker often must grab the can to relocate it nearer the table. The closeness of the shucking tables in one plant prohibited moving the full shell can between the two ends of the table. The can was placed on the table, slid across it, then dumped.

The shucking operation need not contribute to bacterial contamination if properly executed. Placement of clams on the shucking table

should be done only after a receiving space is cleared. The basket should be kept from contacting the table. Perhaps twice a day when the shellstock pile is low the shucker should return, after dumping meats, with a pan of water containing disinfectant to wash the knife and rinse the table surface. The freshly shucked meat should move directly to the pan. One method observed to stop overfilling of the pans was to place an upper limit on the dollar amount to be paid per pan. The amount of time required to transport the full shucking pan to the packing room and return was usually one minute, longer if personal items were attended to.

Packing

The packing process includes receiving freshly shucked meats from the shucker, washing of the meats, and placement of the meats in one of several containers. One man usually operates the packing process for up to approximately 25 shuckers. Additional help was needed for greater than 30 shuckers.

Weighing

Once a shucker has filled his shucking pan with meats, he carries it to the packing room. Here it is dumped onto a skimming table to drain off any excess liquid, Fig. 99. A skimming table consists of a flat surface containing holes recessed into the top of table. When clam meats are placed on the table they are retained while the liquid drains off. Some skimming tables have a spray nozzle suspended over them, Fig. 99, to make it easier to wash the clams.

Once on the skimming table, the clam meats will undergo one of two processes. If the blowing operation is to be used later, the meats are allowed to drain very briefly, then are pushed with a rectangular stainless steel scraper into a weighing container for determination of net weight. If the blowing process is not used, the meats on the receiving-skimming table are rinsed with a water spray while being manually agitated. After draining, these meats are pushed into the

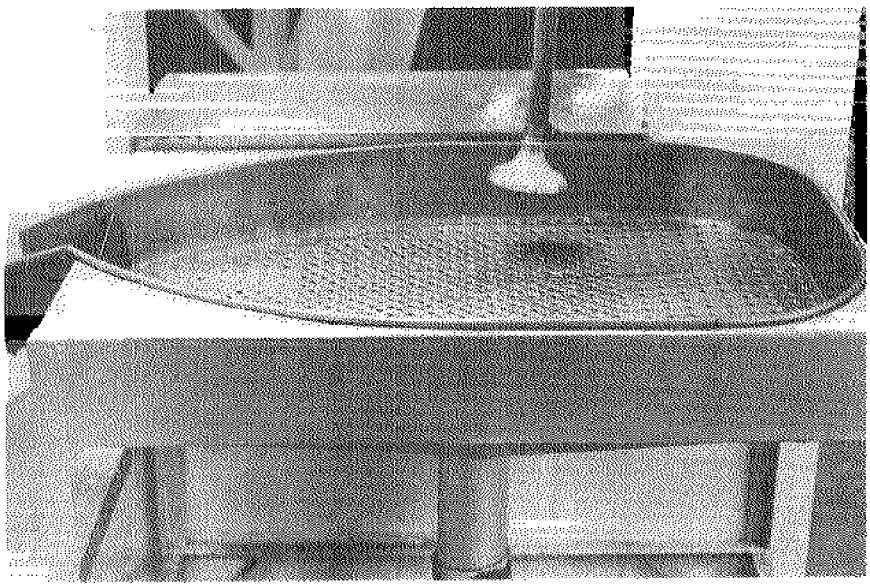

FIG. 99 Receiving-skimming table and spray washer.

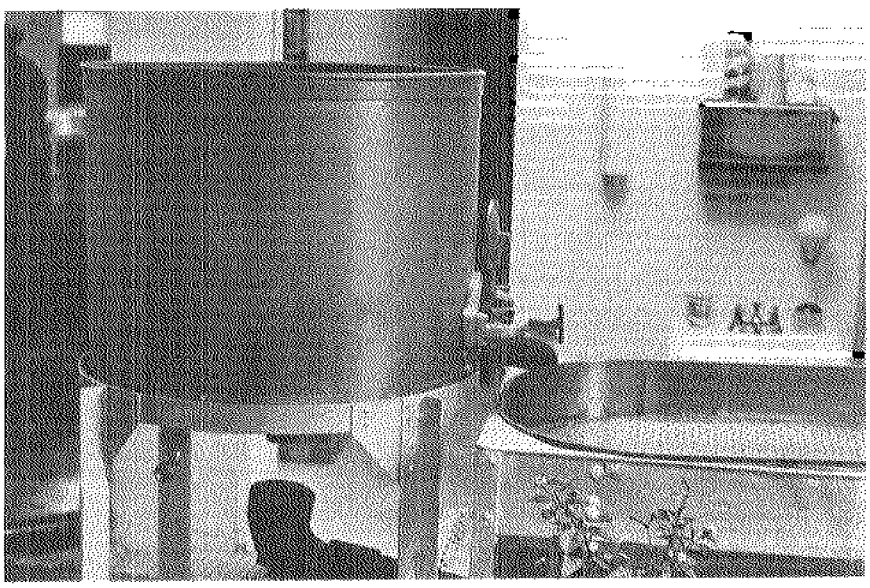

FIG. 100 Elevated blowing tank with gravity discharge port and packer-skimmer table. Right end is similar to that of the receiving table.

weighing container. The weighing container is then manually transferred to the scale by the packing room worker.

Net weight for each separate 2 quart pan of meats is determined to establish shucker compensation. When scale reading is in pounds, a chart is consulted to find the corresponding payment (at 35 cents per pound in 1975). If a supermarket type scale is used, the total dollar payment is read directly from the appropriate cents per pound column on the scale. The shucking payment is recorded on a tally sheet under the shucker's assigned number and verbally communicated to the shuckers, many of whom also record it. Of the plants visited, none had a weighing arrangement such that the shucker could determine scale readings or the zero setting of the scale with an empty container.

After weighing, meats are dumped into a 5 gallon pot for accumulation. Flaked ice might be added to the pot to reduce temperature. The pot is adjacent to the scale and usually not covered. Further cleaning of the meats is done in either of two ways. The least used method was to accumulate about 4 gallons of meats, dump them on the receiving-skimming table and wash them a second time with a water spray and manual agitation. One reason given for washing the meats in the manner described was to reduce the effect of red coloration (discussed above) that was present at the time.

Blowing

The more usual method of cleaning meats is through blowing. Blowing is usually done in a cylindrical tank with a conical bottom and no top. A source of compressed air is piped in at the bottom of the tank and is distributed within the tank through several pipes containing small downward opening holes. Above this air manifold system is a screen to support the meats. A cold water line approaches the tank from above, but stops just above the top edge of the tank to eliminate the chance for back siphoning. A valve on the very bottom of the tank permits draining of all liquid contents. Some blowing tanks have a 5 inch port in the side of the tank just above screen level through which both meats and liquids can flow out of the tank under the force of gravity.

The blowing operation begins by filling the tank with water. Two of the 5 gallon pots of meats are dumped into the tank, the excess water flowing out of the tank and into a drain. Several shovels of flake ice may be added. Air flow is started and maintained for a variable period of time, depending on the plant. Sometimes the clams are manually agitated with a paddle during blowing. Water is added to the point of overflow, then compressed air is turned on for a short period. Floating organics and foam are thus removed. Some meats wash over the side and are either wasted or present a contamination potential as they are placed back in the batch, even though rinsed first.

Blowing affects the meats through water absorption, sand and shell removal as well as bacteriologically. Ward (1969a) found that water absorption increased with increasing blowing time and with lower clam/water volume ratios. Shell removal progressed to the 90-95% level after 10 minutes of blowing, but longer blowing times removed very little additional shell. The higher clam/water ratios inhibited shell removal. Reduction of sand content by blowing was a maximum of 20% in 20 minutes with little likelihood of additional sand removal due to its internal location.

Bacterial levels of commercially blown and spray washed meats were established (Ward, 1969b). Washing was more effective than blowing in reduction of total bacterial level. Neither spray washing nor blowing was consistently effective in reducing total coliform or fecal coliform numbers. Sanitation factors were thought to be a reason for the lack of effectiveness of the blowing process on bacterial reduction.

Pilot plant studies were conducted (Ward, 1969c) to measure the effect on the bacterial levels of blowing water that was: sterile, inoculated, chlorinated, reused or refrigerated. Clams blown in sterile water were always lower in bacterial levels than unblown clams. Inoculation of blowing water increased the level of bacteria over that for clams blown in sterile water. Chlorinated water showed no effect for blowing times of 3 minutes or less, but did reduce bacteria numbers with longer blowing times. Reuse of the blowing water increased the plate count levels, but decreased total coliform and fecal coliform levels. Use of refrigerated blowing water resulted in bacterial levels slightly less than for room temperature tests.

From the blowing tank the meats are transferred to the packer-skimmer table. When the blowing tank is situated at floor level the meats must be bailed out by bucket down to the last inch, then the bottom screen is lifted out and the remainder of the meats are scraped off. Most blowing tanks were adjacent to and elevated above the packer-skimmer table (Fig. 100). A 5 inch port in the side of the tank permits gravity flow of meats and water from tank to the packer-skimmer table.

Can Filling

Meats on the packer-skimmer table are allowed to drain briefly, usually while cans are being prepared. Meats are informally inspected and obvious large shell fragments might be manually picked out. Empty gallon cans or 5 gallon pots are placed under the discharge chute and meats are scraped into the container. If over-filled, meats are manually taken from the can and returned to the table supply. The usual batch is 10 to 12 gallons. Any particles of ice still in the meats also go into the can. The last meats of a batch will only partly fill a can, which is then left on the table to be topped off as the first gallon of the next batch. After all have been filled, the snap lids are placed on the gallon cans or loose fitting lids placed on the five gallon pots. Cans are coded to identify plant and date and are further identified with the product species. A gallon of meats is defined as 8.5 lb.

Handling methods for full gallon cans varied considerably. In one plant the procedure was to place a layer of ice in a bushel basket, set four cans in the basket, drag the basket into the cooler, than add more ice on top. Or, the cans from one batch might be placed on a small push-cart for transport to the cooler, then placed on slats in the cooler. In another plant up to 90 gallons were accumulated on a larger push truck within the packing room. These clams remained in the packing room throughout most of the shucking period. Some ice was placed on top of the cans on the top layers.

Potential Packing Room Problems

Much potential for contamination occurs during the packing operation. The blowing tank is rinsed while meats are on the packer-skimmer table, allowing splash water to contact the meats. Unfilled and open gallon cans sit upright on the filling table subject to splash from rinsing operations. Lids for the gallon cans were knocked to the floor then used directly to close cans. The water hose used periodically to rinse the floor was dragged across the packing table, the same surface used to store lids prior to sealing. Portions of clam meats were observed to be pinched between the lid and the can during sealing, leaving a portion of the meat outside of the can.

Ice is manufactured overhead and falls into a floor level bin within the ice room. It is used on a last-in-first-out basis with the result that much of the ice might be in open storage or against the floor for long periods of time, subject to contamination. The ice used in direct contact with the meats (5 gallon pot and blowing tank) will possibly be transported in a wheelbarrow incapable of being sterilized or with a scoop shovel used at other times to shovel clams from the floor.

An ice supply less subject to risk of contamination may be achieved as follows. Locate a hopper, of sufficient size to contain the ice requirements for about 2/3 of a day's operation, within a refrigerated room adjacent to the packing room. Allow ice to fall directly into the hopper from the ice making machine. Ice overflow from the hopper could fall directly onto the floor of the refrigerated room. Ice in the hopper would be subject to much less risk of contamination, especially since it should receive nearly a complete daily clean out. Providing access to the ice in the hopper through a waist level door located in the packing room near the points of ice usage would provide convenience and reduce the tendency to use the wrong shovel (e.g., one from the shellstock area) to secure ice. Overflow ice falling to the cold room floor could be used to ice sealed containers of meats as is presently done.

Splash contamination of empty cans could be significantly reduced by constructing a rack above the packing table to store empty gallon

cans in an upside down position. Thus, the cans are within easy reach of an individual working next to the packer-skimmer table and are less subject to spray water contamination. Lids should be stored next to the cans in a rack having a shield between the lids and any source of spray water from the direction of the blowing tank.

Waste Removal from Shucking Plant

The waste products of the shucking operation are shells, clam siphon, siphon skin and liquids. The shells, skin and siphon are dropped to the table in front of the shucker. The pile is periodically pushed from the table into a garbage can or bushel basket. Shuckers handle these containers then continue shucking. One other method of shell removal is to place a longitudinal conveyor under each row of tables. An inclined sheet metal slide connects the conveyor to just outside the edge of the table. Shells then drop on the slide or the edge of the table and from the latter are easily pushed into the slide. Some difficulty was encountered in getting the waste products to slide properly. Solid wastes are moved from the plant by conveyor and/or wheelbarrow to a dump truck and, after a shucking run, are hauled to a hog farm on a give-away basis.

Liquid wastes are generated by the shucking operation: from draining, washing and blowing of the meats; from washing of the bushel baskets; from ice melt in the cooler; and from plant cleanup. Plants situated on an estuary usually discharge these liquids directly into the water after passing through a 20 mesh screen and a chlorination process. Inland plants after screening and chlorination run the wastes directly into a drainage ditch or into a lagoon constructed for the purpose. Some plants are connected to a city sewer system.

Breading of Soft Clams

The safe storage period for shucked clam meats is limited. For example, Rosen (1966) reported on the increase in acidity that occurs during cold storage of clam meats. Shucked fresh meats are utilized by

restaurants where they are deep fried just prior to use. Meats are also breaded, fried, frozen and packaged in individual servings. This considerably increases storage life and cooking convenience at the point of use. Following is a brief description of the equipment and process used in the breading and freezing operation. Fig. 83 shows the operations process chart for this process.

Freshly shucked meats arrived at the plant in 5 gallon plastic or stainless steel pots. The pots were refrigerated at 38°F to be processed within 24 hours. Checks were made for net weight per gallon, drained weight per gallon, count per gallon (both whole and pieces) and the number of oversize clams. Quality checks were made for shell fragments, sand, temperature and odor. Clams containing red coloration were washed to reduce the possibility of a red stain in the breading.

A pot of meats, without being drained, was dumped into a plastic tray called a lug. A batter of flour and water was added and mixed by hand. Breading was added in a rotating drum. The drum, constructed of stainless steel, was about 20 inches in diameter and 60 inches long. The breading material was fed mechanically to the drum at a constant rate with approximately 100 pounds of breading in the drum at any one time. A lug of battered meats was dumped on an elevated table adjacent to the input end of the breading drum and manually fed into the drum by an operator standing on an elevated platform.

The breaded meats discharged from the drum fell onto a small elevating conveyor over which was mounted a large padded wheel that pressed on the material to aid in breaking up pieces containing two or more pieces of meat. An operator was stationed at this conveyor to manually stir the breaded product and further check for conglomerate masses.

The inclined conveyor dropped the breaded product into the culling device, or vibrating shaker, consisting of a flat stainless plate perforated with approximately 1/2 inch holes and slightly inclined from the horizontal. Here excess breading was removed as well as the small pieces of breaded meat not useful in the finished product. The breading thus removed was further screened with a screen having approximately 3/16 inch holes. Material passing over this screen,

assumed to be small particles of meat coated with breading, were consigned to waste. A doughball also dropped off the screen to waste. Particles of breading passing through the 3/16 inch screen were automatically recycled to the breading supply for reuse.

From the culling device, the breaded clams go to the fryer. The fryer was a one million BTU natural gas unit maintaining 100 gallons of soybean cooking oil held at 350°F. Retention time for blanching in the fryer was 10 seconds. Oil was added continuously for an estimated oil turnover of 12 hours but was not changed as a batch. The oil was continuously passed through a paper filtering system. A drag conveyor along the bottom scraped out small particles falling through the screen that carried the product. Extended retention of these small particles burned them producing an off-flavoring in the product.

From the fryer the product was transported to the freezer on a 30 foot inclined conveyor. This served to precool the product and was necessary to boost freezer capacity. The first 1/3 of the conveyor was exposed while the final 2/3 was covered with ductwork housing a refrigeration and forced air system.

The product was frozen in a blast freezer. Four open stainless steel belts carried the product back and forth through the freezer twice. The product was dropped from the first belt to the second belt, etc., in order to break up frozen groups. Temperature was maintained at -40°F with an approximate wind velocity of 44 ft/sec and a retention time of 25 minutes.

Further vibratory screening was used after the freezer. This unit consisted of closely spaced inclined rods as well as perforated plates which allowed small pieces to fall through. Small pieces that were formerly thrown away are now packaged as a snack. Larger pieces left the freezer via an inclined conveyor towards the weighing and bagging unit. Several employees were positioned along the conveyor to sort out small pieces and break up groups of several pieces that might have been frozen together.

The conveyor load of frozen pieces was mechanically divided into three channels, each feeding a weighing unit. The product was packaged in single serving plastic bags having a net weight of 4 to 6 oz.

Accurate establishment of net weights was difficult due to the irregular shape of the product and heavy weight of each piece relative to package net weight. All packages of finished product were manually checked for over/under weight by plant personnel. The large number of incorrectly filled packets were passed to another operator who opened the package, corrected the weight then resealed it.

The finished frozen product went to the restaurant trade. This market demands a whole single clam. One pound of meats going into the plant, with the addition of oil and breading will generate about 2 pounds of product plus some wastes. Obviously, this ratio varies with the breading used and market needs.

The breading and freezing industry processed mostly soft shell clam meats prior to Tropical Storm Agnes in June 1972. A shortage of soft clams occurred and customers accepted strip clams as a substitute. The strip clam is cheaper than the soft clam but is not of the same quality. The soft clam again returned to the market but was not purchased due to the excessive price differential over the strip clam.

Shell Size Versus Component Weights of Soft Clams

The relationship between shell length and the weight of the meat, shell halves and siphon was established. Groups of 100 clams originating from each of 5 harvest areas were refrigerated for two days before processing. All clams used were of legal size (2 1/4 inches minimum length at the time) to be representative of those entering the commercial market. Feder and Paul (1974) conducted a similar study for clams from Prince William Sound, Alaska. They considered the full age spectrum, including juveniles, of a clam population which matures much less rapidly than the clams of the Chesapeake Bay.

For each clam a determination of live weight and shell length was made after shucking. The meat, shell halves and siphon were placed on a perforated plate to permit drainage of surface water. Weight of each individual component was determined to the nearest 0.1 gram. Total wet solids weight of the clam was calculated by the numerical addition of the weight of shell, meat and siphon (including also the skin). The difference between the live weight and the wet solids weight is the weight of free water retained by the clam.

Table 33 gives the mean and standard deviation by location and for all locations taken together for each clam component. In addition to this analysis least squares linear regression equations were calculated for the following variables:

1. shell length versus live weight
2. shell length versus shell weight
3. shell length versus siphon weight
4. shell length versus meat weight
5. shell length versus solids weights
6. live weight versus shell weight
7. live weight versus siphon weight
8. live weight versus meat weight
9. live weight versus solids weight

These regressions were carried out by harvest location to determine differences due to location. Table 34 shows the significant differences for both slopes and intercepts of the regression lines. Values with the same superscript within a set are not significantly different from each other. Thus, the slopes for the five regressions of shell length versus live weight are not significantly different from each other. The same is true for the slopes of shell length versus shell weight and live weight versus solids weight regressions. Intercepts for all sets show significant differences. Thus, the data from the five locations cannot be combined.

The regression equations relating shell length with live weight can be taken directly from Table 34. The regression equation for the Shaw Bay data can be written as:

shell length in inches = -62.7 + 35.9 (live weight in grams).

Similarly, equations can be written for the other locations and clam body components by taking the appropriate slope and intercept from Table 34. Example plots of the Shaw Bay data are shown in Appendix E.

TABLE 33. MEAN AND STANDARD DEVIATION OF SHELL LENGTH AND COMPONENT WEIGHTS OF MARKET SIZED SOFT CLAMS FROM FIVE HARVEST LOCATIONS

Component	TEST DATE AND HARVEST AREA											
	3/13/75 Shaw Bay		5/28/75 Marshy Point		6/19/75 Beverly Beach		6/26/75 Saunders Point		8/6/75* Middle Ground		All Locations together	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Shell Length (in.)	2.7	0.2	2.7	0.2	2.6	0.2	2.6	0.2	3.0	0.2	2.7	0.3
Live Weight (g)	32.3	7.6	34.9	10.4	29.3	9.1	31.0	9.3	46.6	11.2	34.9	11.4
Shell Weight (g)	8.2	1.9	9.4	2.6	8.5	2.6	8.3	2.4	12.0	2.8	9.3	2.9
Siphon Weight (g)	4.8	1.2	4.7	1.4	3.7	1.1	4.4	1.5	6.5	1.6	4.8	1.7
Meat Weight (g)	9.6	2.7	11.2	4.0	7.7	2.9	8.0	2.9	13.5	4.2	10.0	4.0
Solids Weight (g)	22.6	5.5	25.3	7.6	19.8	6.3	20.6	6.3	32.0	7.9	24.1	8.1
Free Water (g)	9.8		9.7		9.5		10.4		14.6		10.8	

*Middle Ground is located on the west edge of the shipping channel directly east of Shadyside, Maryland.

TABLE 34. SLOPES, INTERCEPTS AND CORRELATION COEFFICIENTS FOR LINES RELATING VARIOUS SOFT CLAM BODY COMPONENTS AND/OR SHELL LENGTH. SHELL LENGTH IS IN INCHES AND ALL WEIGHTS ARE IN GRAMS. REGRESSIONS ARE OF THE FORM $y = a + bx$.

variable x	variable y	location*	slope (b)	intercepts (a)	r
shell length	live weight	1	35.9^{a}	-62.7^{a}	0.86
		2	38.7^{a}	-70.7^{a}	0.85
		3	33.3^{a}	-56.6^{a}	0.89
		4	37.0^{a}	-65.3^{a}	0.86
		5	41.2^{a}	-75.0^{b}	0.81
shell length	shell weight	1	9.0^{a}	-15.6^{a}	0.84
		2	9.7^{a}	-17.0^{b}	0.84
		3	9.1^{a}	-15.0^{ab}	0.86
		4	9.5^{a}	-16.6^{b}	0.87
		5	10.9^{a}	-20.2^{b}	0.85
shell length	siphon weight	1	4.7^{ab}	-7.7^{ab}	0.74
		2	4.9^{ab}	-8.6^{ac}	0.77
		3	3.4^{a}	-5.2^{c}	0.77
		4	5.5^{b}	-9.9^{a}	0.82
		5	4.7^{ab}	-7.4^{b}	0.65
shell length	meat weight	1	11.7^{ab}	-21.6^{a}	0.78
		2	13.7^{a}	-26.1^{b}	0.77
		3	9.5^{b}	-16.7^{b}	0.80
		4	10.8^{ab}	-20.2^{b}	0.82
		5	14.4^{a}	-29.1^{a}	0.76
live weight	shell weight	1	0.24^{ab}	0.52^{a}	0.93
		2	0.23^{ab}	1.39^{bc}	0.90
		3	0.27^{a}	0.58^{b}	0.95
		4	0.23^{ab}	1.01^{ac}	0.92
		5	0.22^{b}	1.68^{ac}	0.89
live weight	siphon weight	1	0.12^{ab}	0.89^{a}	0.79
		2	0.12^{ab}	0.52^{b}	0.86
		3	0.10^{b}	0.71^{c}	0.85
		4	0.14^{a}	0.74^{ab}	0.87
		5	0.12^{ab}	1.15^{a}	0.81
live weight	meat weight	1	0.32^{ab}	-0.93^{b}	0.90
		2	0.34^{a}	-0.83^{c}	0.88
		3	0.28^{ab}	-0.46^{a}	0.88
		4	0.27^{b}	-0.56^{a}	0.89
		5	0.31^{ab}	-1.13^{ab}	0.84

TABLE 34. CONTINUED

variable x	variable y	location*	slope (b)	intercepts (a)	R
shell length	solids weight	1	25.4^{ab}	-44.8^{abc}	0.85
		2	28.2^{ab}	-51.8^{ac}	0.85
		3	22.0^{a}	-36.8^{ab}	0.86
		4	25.8^{ab}	-46.6^{b}	0.88
		5	30.0^{b}	-56.7^{c}	0.83
live weight	solids weight	1	0.68^{a}	0.48^{ab}	0.94
		2	0.69^{a}	1.08^{b}	0.94
		3	0.65^{a}	0.83^{ac}	0.94
		4	0.64^{a}	0.60^{c}	0.94
		5	0.65^{a}	1.71^{ac}	0.92

*location 1 is Shaw Bay
location 2 is Marshy Point
location 3 is Beverly Beach
location 4 is Saunders Point
location 5 is Middle Ground

Regressions relating the variables noted in Table 34 were also developed using a logarithmic value of the Y variable. Only in a few instances did this improve the fit of the regression curve to the data, and then only a minor amount. Thus, there was no justification and/or advantage in using a semilogarithmic plot.

The average percentage of live weight made up of the various parts of the clam can also be calculated. Table 35 shows the result of calculating these percentages from the data shown in Table 33. Meat weight, that part of the clam used for human consumption, comprises only about 25 to 32 percent of the total clam. Thus, a well-drained 56 pound bushel of clams will yield about 14 to 18 pounds of meat. Free water which is lost upon shucking makes up approximately 30 percent of the live weight. The siphon accounts for about 12 to 15 percent of the live weight. Although the siphon is edible it is presently discarded because of its tough texture. Developing products which utilize the clam siphon may be a profitable investment for the industry. Shell weight makes up the remaining 25 to 29 percent of the

live weight. Shells are presently discarded, but it is also possible that these could be utilized in some manner to bring a return to the processing plant.

TABLE 35. PERCENT OF LIVE WEIGHT MADE UP BY VARIOUS PARTS OF THE SOFT-SHELL CLAM BY HARVEST LOCATION. PERCENTAGE CALCULATIONS WERE BASED ON THE MEAN VALUES SHOWN IN TABLE 36.

	Test Date and Harvest Location					
Component	3/13/75 Shaw Bay	5/28/75 Marshy Point	6/19/75 Beverly Beach	6/26/75 Saunders Point	8/6/75 Middle Ground	All locations together
shell weight	25.4	26.9	29.0	26.8	25.8	26.6
siphon weight (including skin)	14.9	13.5	12.6	14.2	13.9	13.8
meat weight	29.7	32.1	26.3	25.8	29.0	28.7
solids weight	70.0	72.5*	67.6*	66.5*	68.7	69.1
free water	30.0	27.5	32.4	33.5	31.3	30.9

*The percent solids weight may be slightly different than the sum of the percent shell weight, siphon weight and meat weight due to rounding of numbers used in calculating each percentage.

VII. CONCLUSIONS

1. If clams are harvested above acceptable bacterial limits, this level will not be reduced in the fresh meats with normal processing. Nonnormal processing might include the use of chlorine in the blowing tank. Thermal processing after shucking will also affect bacterial levels.

2. Observation of shucking plants revealed no single production practice as being the cause of high bacterial levels in the fresh meats. However, there were many unsanitary practices and poor management functions all of which could add to the bacterial levels or be extremely serious should a more lethal organism be present at the time of the sanitation infraction. Some of the poor practices observed included:

   a. Clams harvested in used baskets which were not cleaned.
   b. Clams transported in an unrefrigerated truck covered with an unclean tarpaulin.
   c. Baskets of clams separated by and coming in contact with wooden racks or sticks. During storage, the dripping of fluids from one basket to the one below it.
   d. Improper refrigeration temperatures.
   e. Failure to shuck all of the clams in a pile prior to adding additional clams to the pile.
   f. Overfilling of shucking pans to the points where meats fell off and were then returned to the pan.
   g. Smoking by the shuckers while shucking.
   h. Unclean utensils.
   i. Precooling of meats with ice previously in contact with a concrete floor.
   j. Use of this same ice during blowing.
   k. Use of an ice shovel that was previously used to shovel spilled shellstock.
   l. Use of a standard steel wheelbarrow to transport ice later used in the blowing operation.

m. Splashing of rinse water on clam meats prior to packing.
n. Contamination of lids and cans by splash water and by falling to the floor.
o. Temporary but relatively long term storage of canned meats in the packing room prior to placement in iced storage.

3. Soft shell clams are generally sold either as fresh in the shell, fresh shucked or breaded and frozen.

4. An average soft clam shucker will shuck between 0.5 and 0.6 bushels/hour when measured over a full day or longer time period.

5. Figures 82 and 83 give an operations-process chart for the Maryland soft shell clam industry.

6. Typically, walk-in refrigerated facilities in the Maryland soft shell clam industry will cool bushel baskets of clams from 80°F to 50°F in 10 to 14 hours.

7. It appears significant (14% in one basket) quantities of soft clams are being damaged by cracking or breaking prior to shucking. This appears to be a significant economic loss.

8. The shading of full baskets of clams on board harvesting boats significantly lowers clam temperature on hot, sunny days.

9. The soft clam dredge appears to have been developed by a trial and error process. Thus, a detailed engineering study of dredge design may result in significant energy savings and reduction in operating costs.

10. Significant improvements could be made in the transportation of soft shell clams which should improve clam quality.

11. Relationships between soft clam shell length and 1) weight of the clam meat, 2) weight of clam siphon and 3) total clam wet solids weights were developed. Similar relationships relating live clam weight to these three values were also developed. The regression relationships are shown in Table 34.

12. A well-drained 56 pound bushel of soft clams generally yields 14 to 18 pounds of usable meats.

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APPENDIX A

Plate Count, Total Coliform Counts and Fecal Coliform Counts as a Function of Time After the Soft-Shell Clams were Placed in a Constant Air Temperature Environmental Chamber.

Appendix A-1

Spring 1973

Plate Counts at
40, 50, 60, 70, 80, 90°F

Total Coliform Counts at
40, 50, 60, 70, 80, 90°F

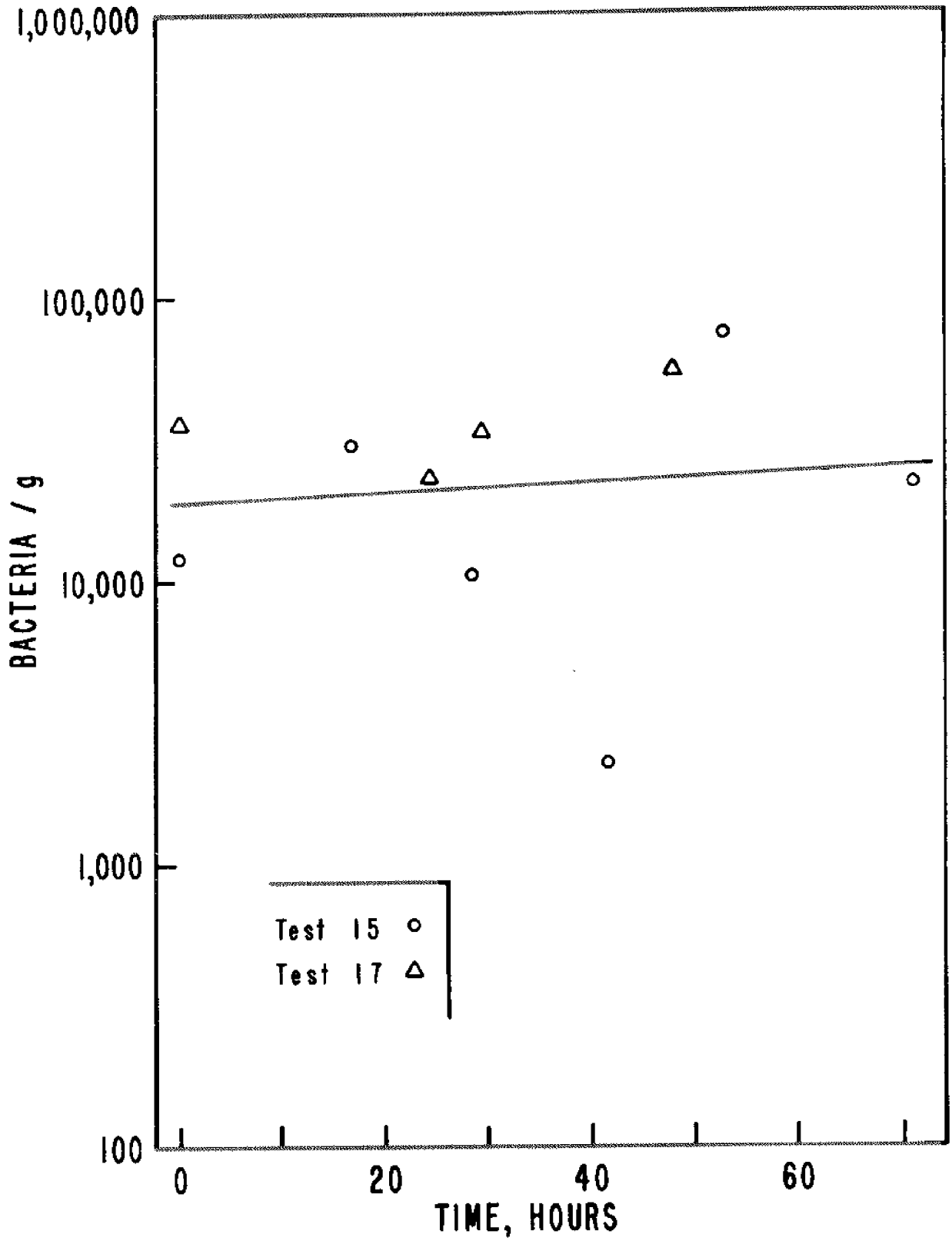


Plate count as a function of time for clams harvested during Spring 1973 and held at a constant temperature of 40°F.

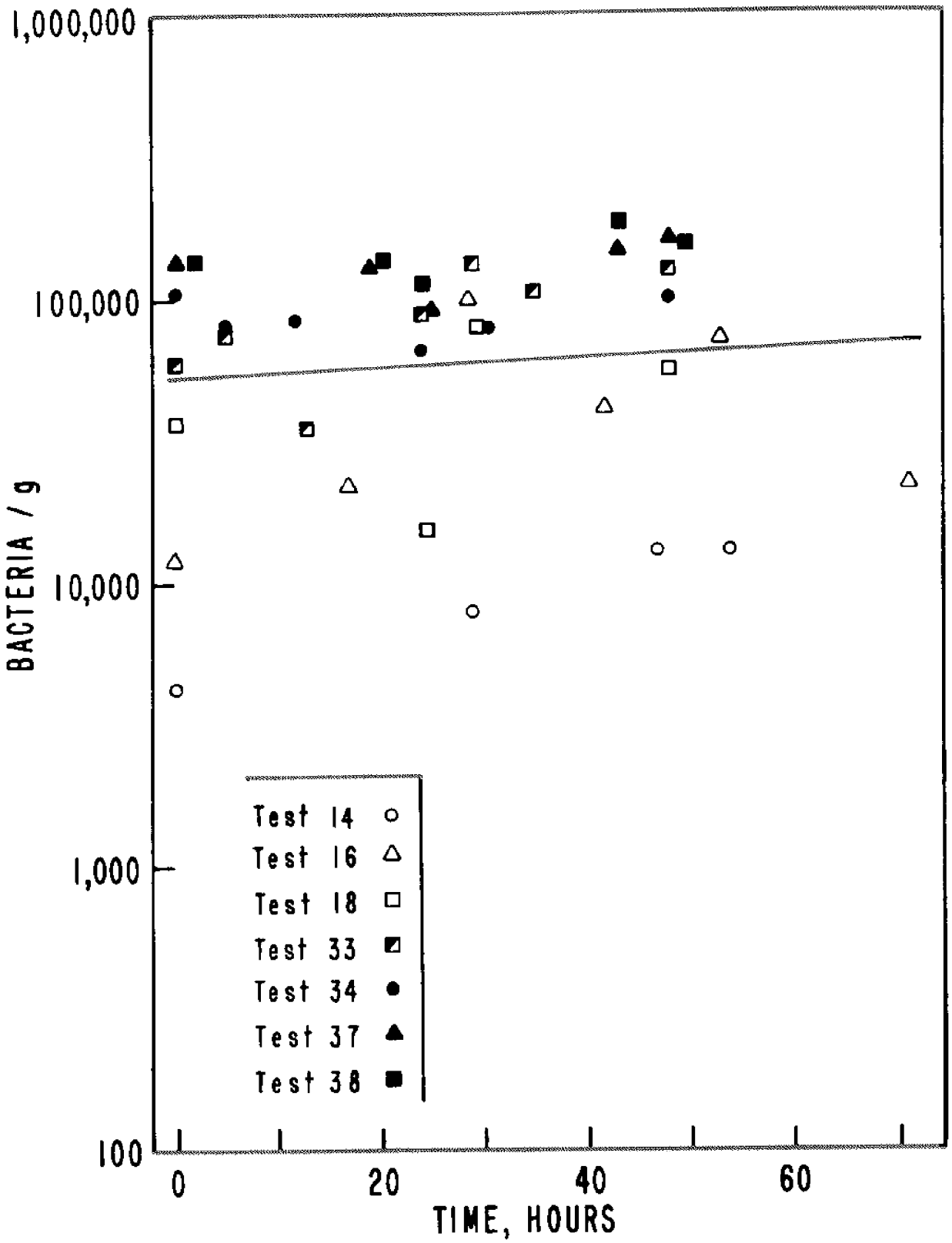


Plate count as a function of time for clams harvested during Spring 1973 and held at a constant temperature of 50°F.

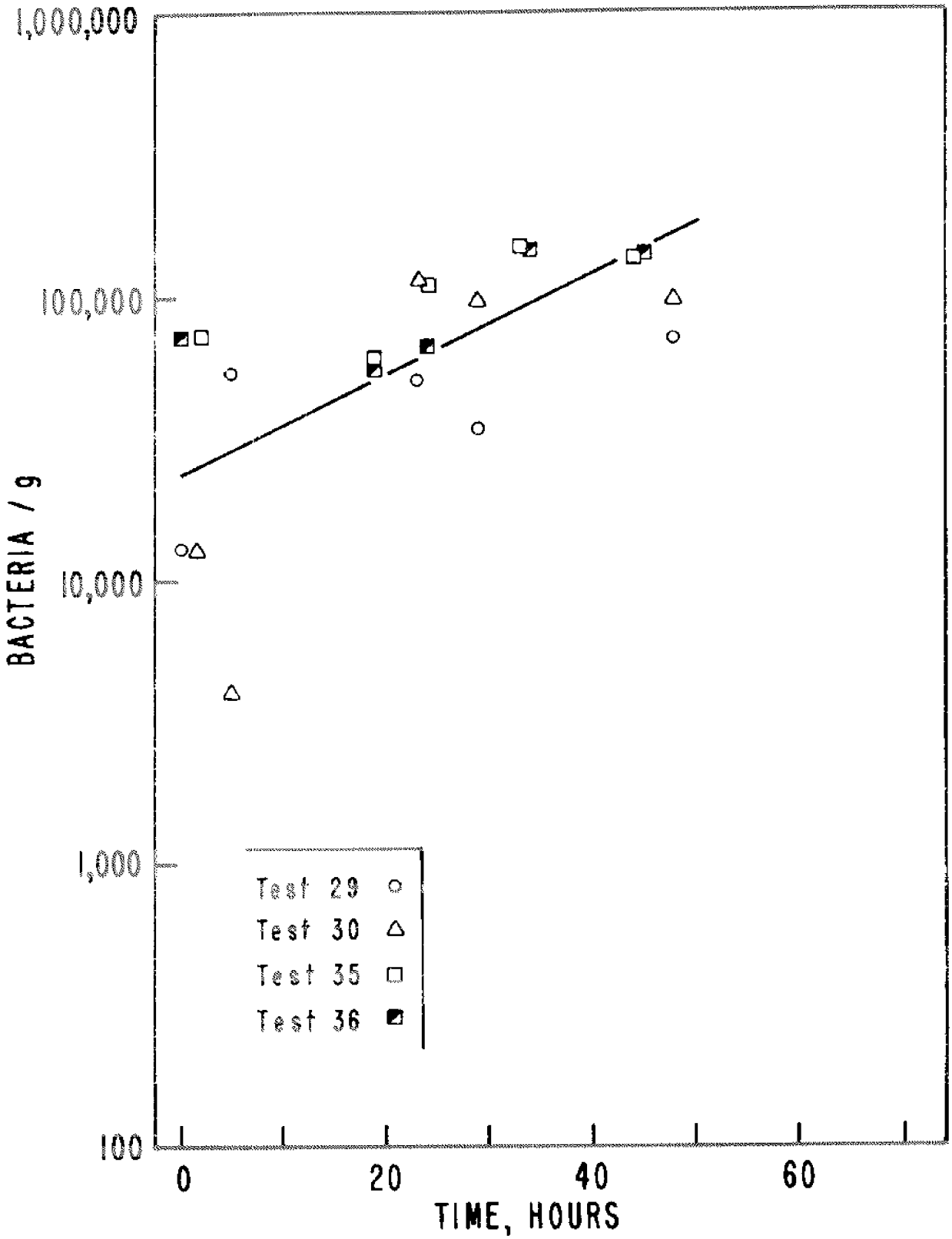


Plate count as a function of time for clams harvested during Spring 1973 and held at a constant temperature of 60°F.

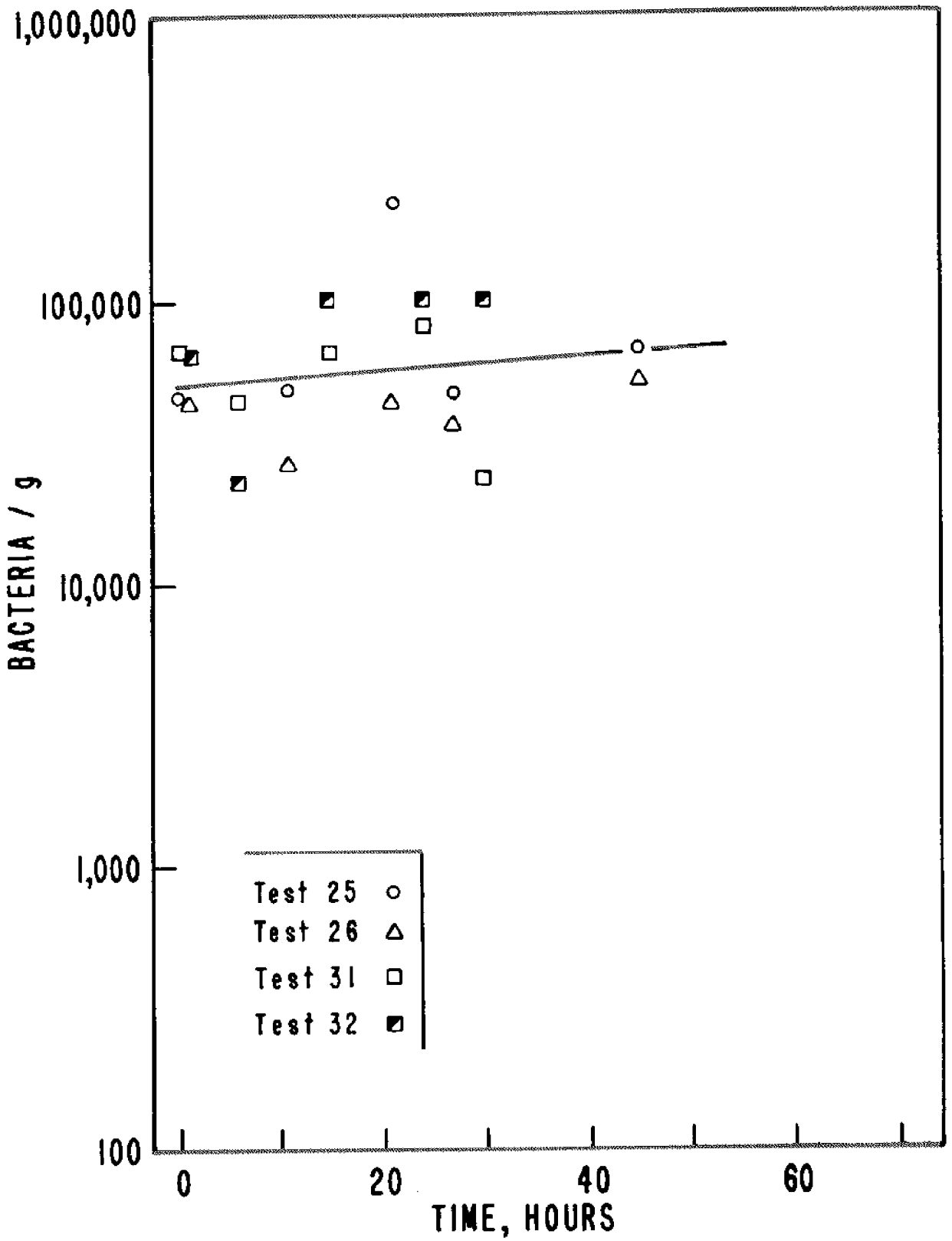


Plate count as a function of time for clams harvested during Spring 1973 and held at a constant temperature of 70°F.

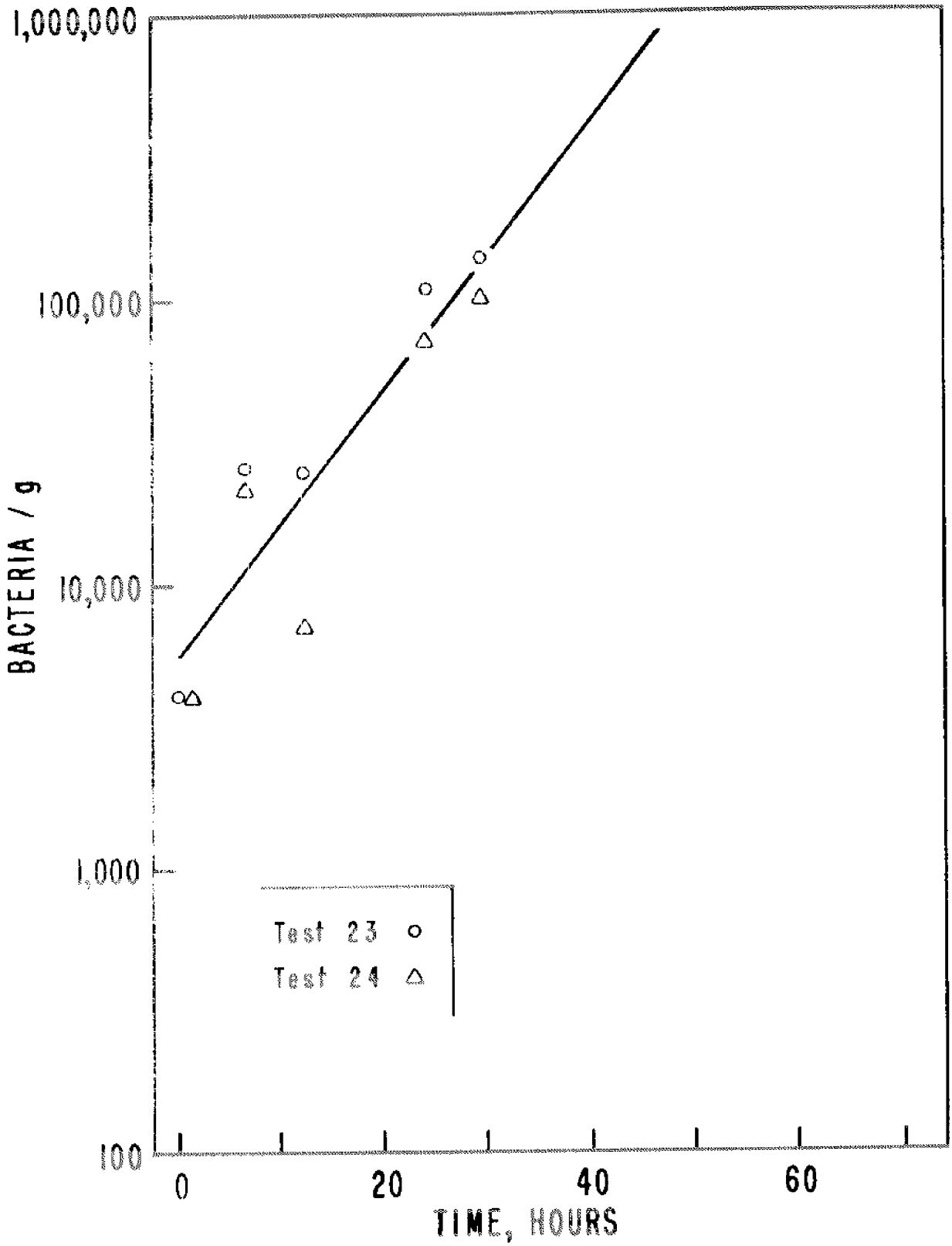


Plate count as a function of time for clams harvested during Spring 1973 and held at a constant temperature of 80°F.

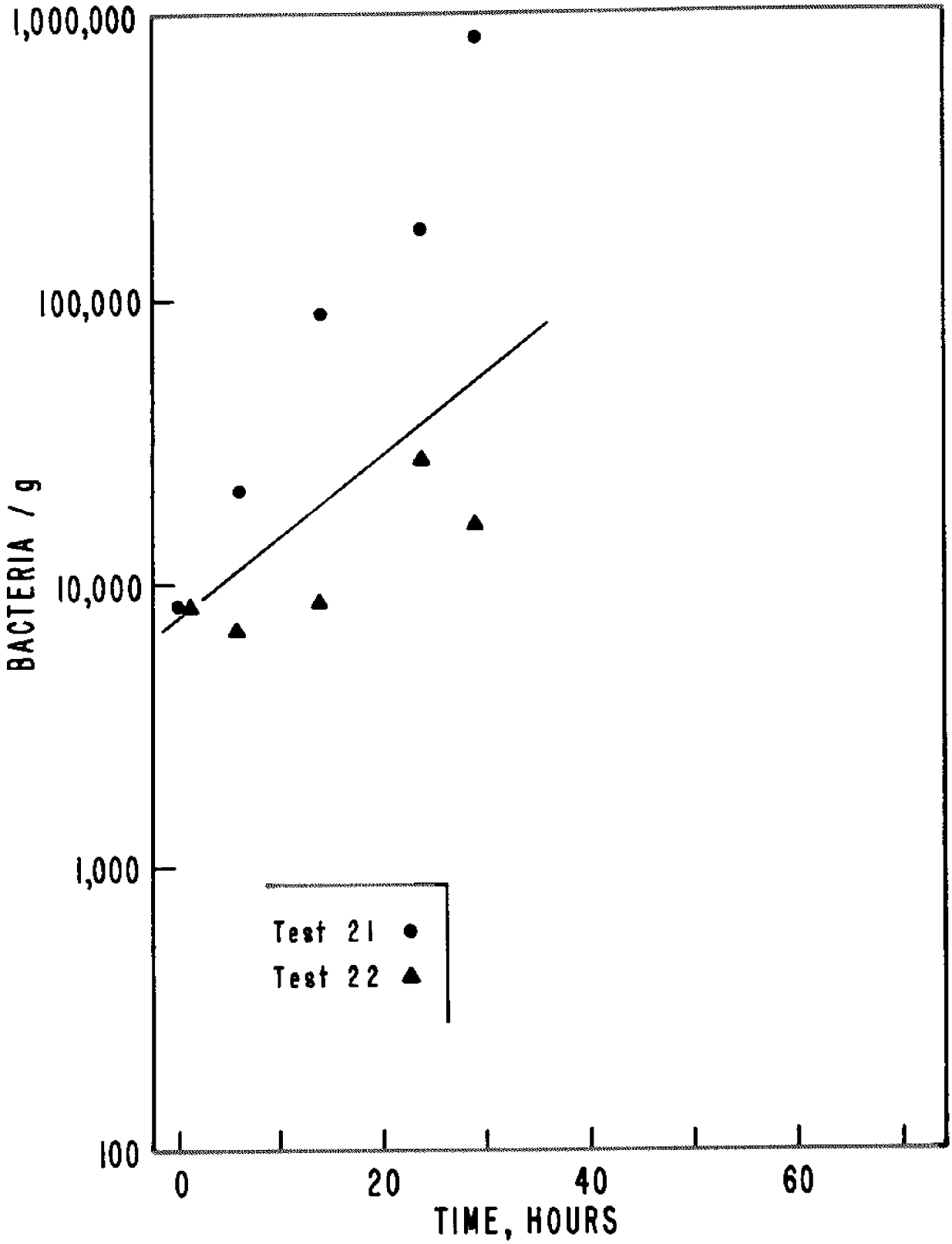
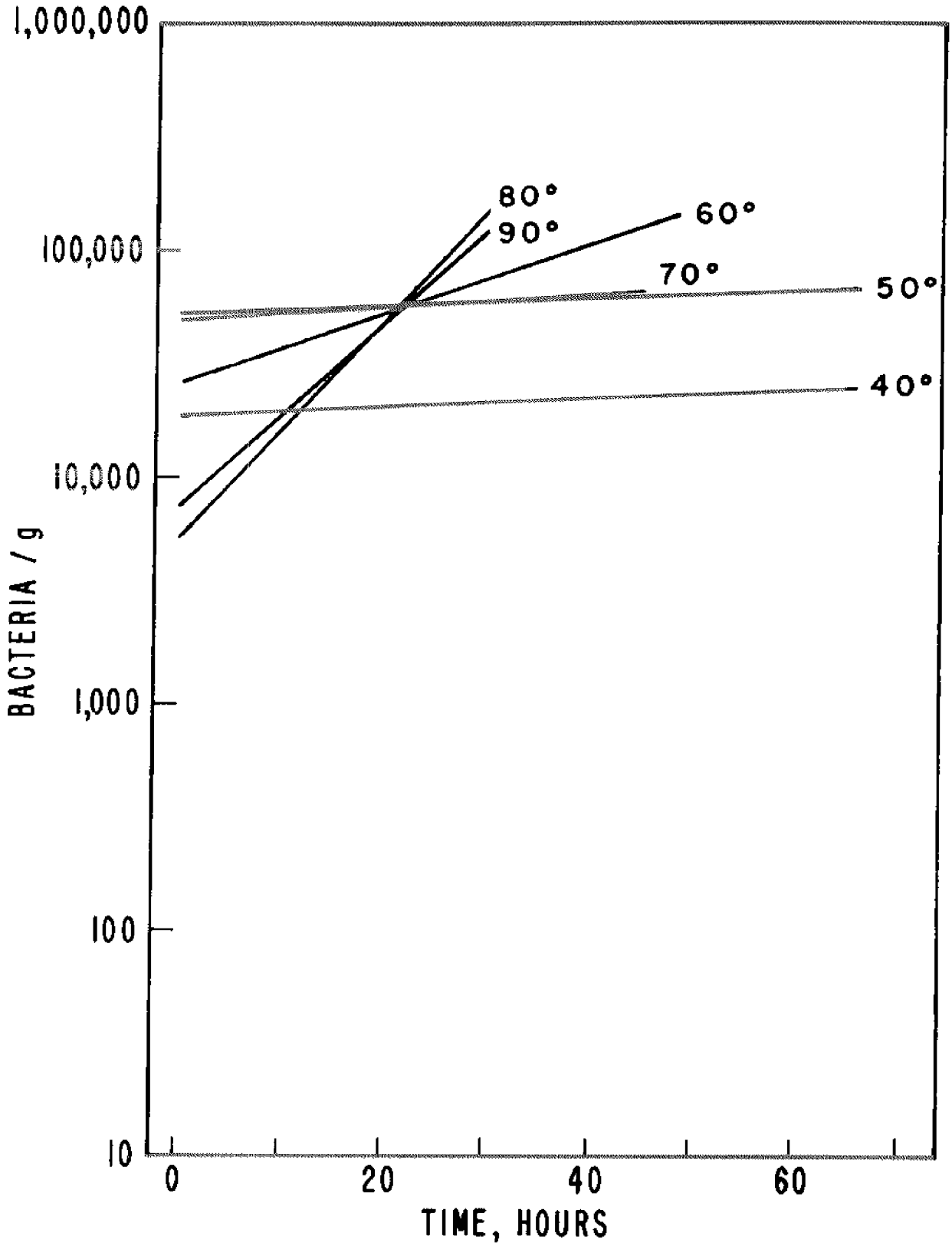
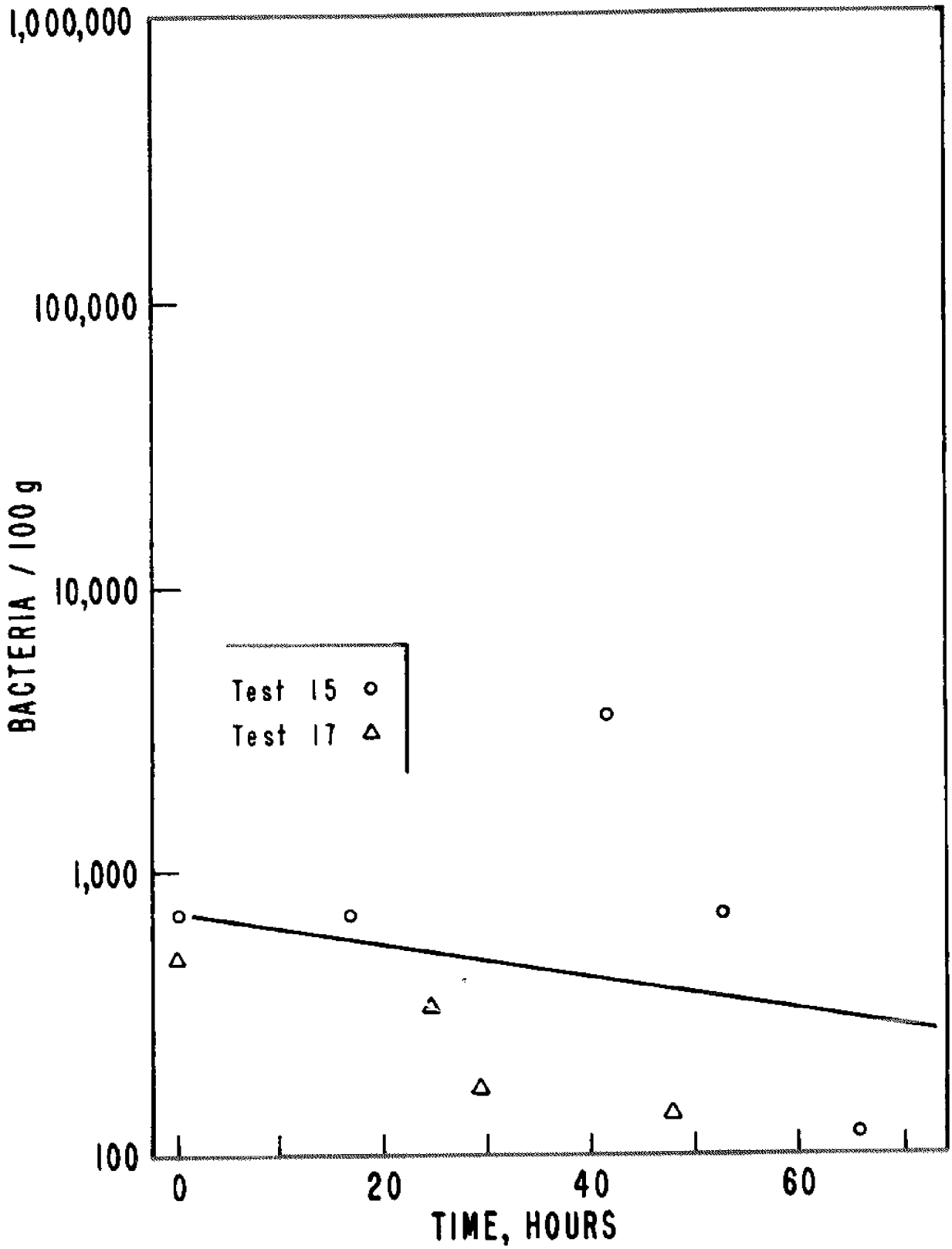


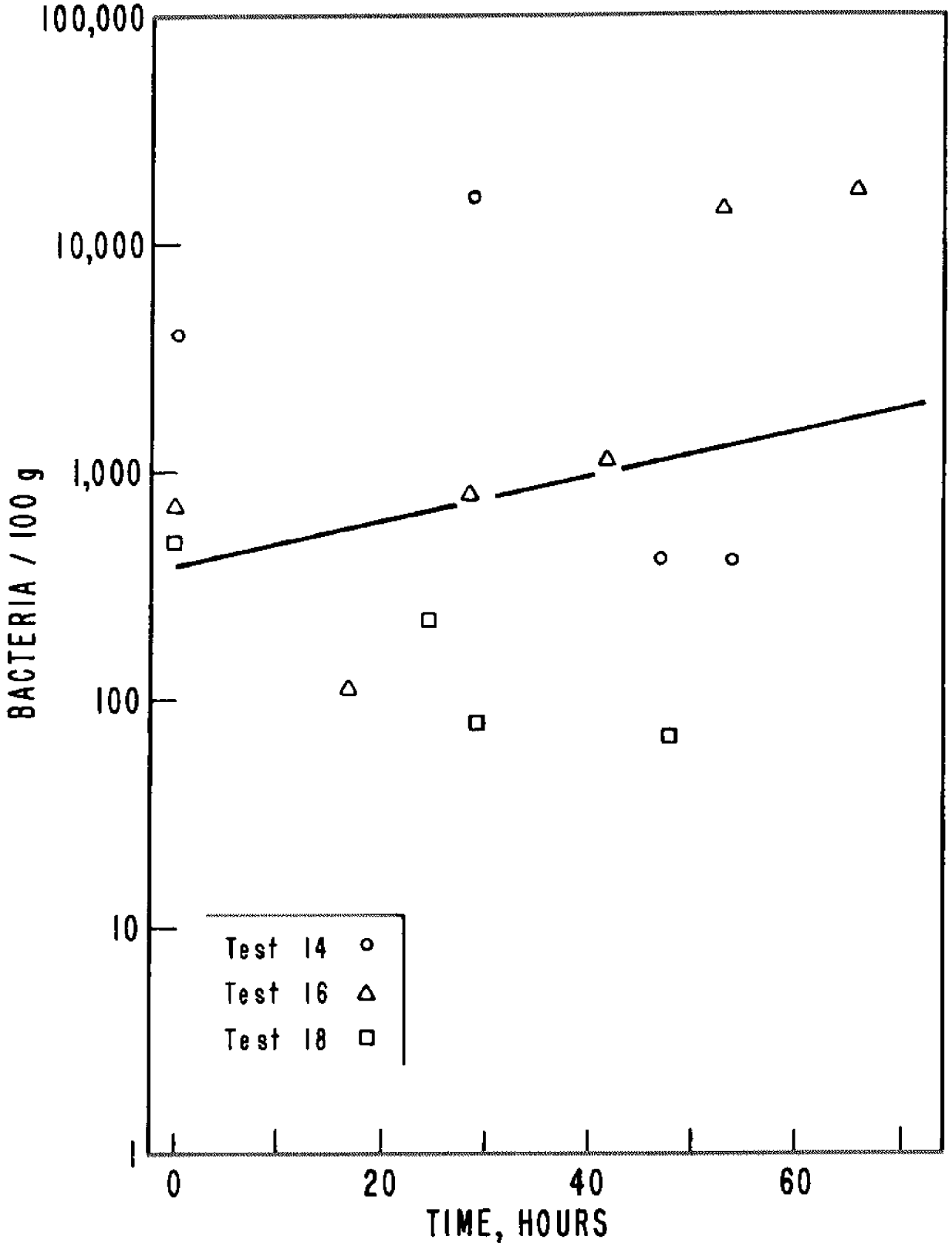
Plate count as a function of time for clams harvested during Spring 1973 and held at a constant temperature of 90°F.



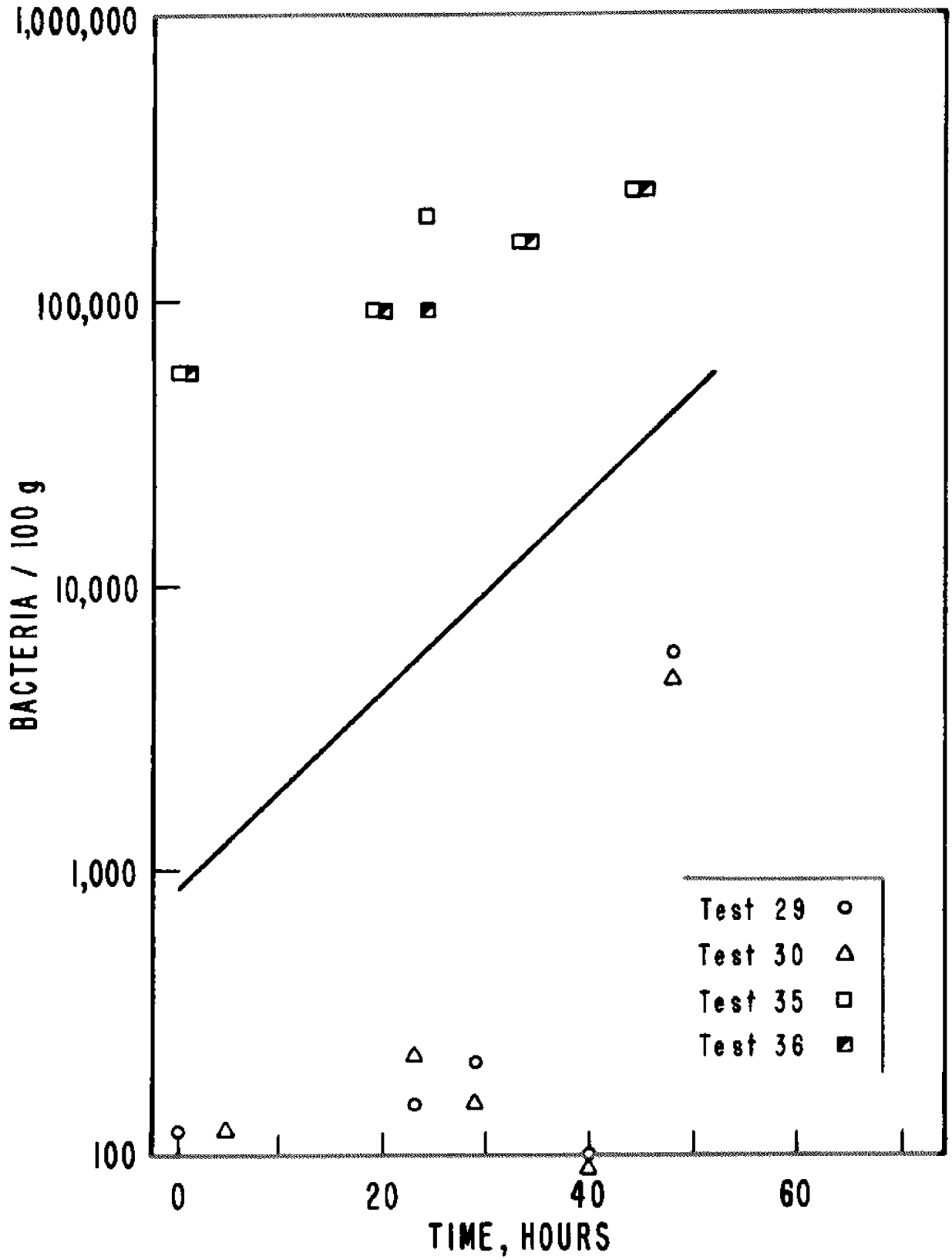
Summary of plate counts as a function of time for clams harvested during Spring 1973 and held at the indicated temperatures.



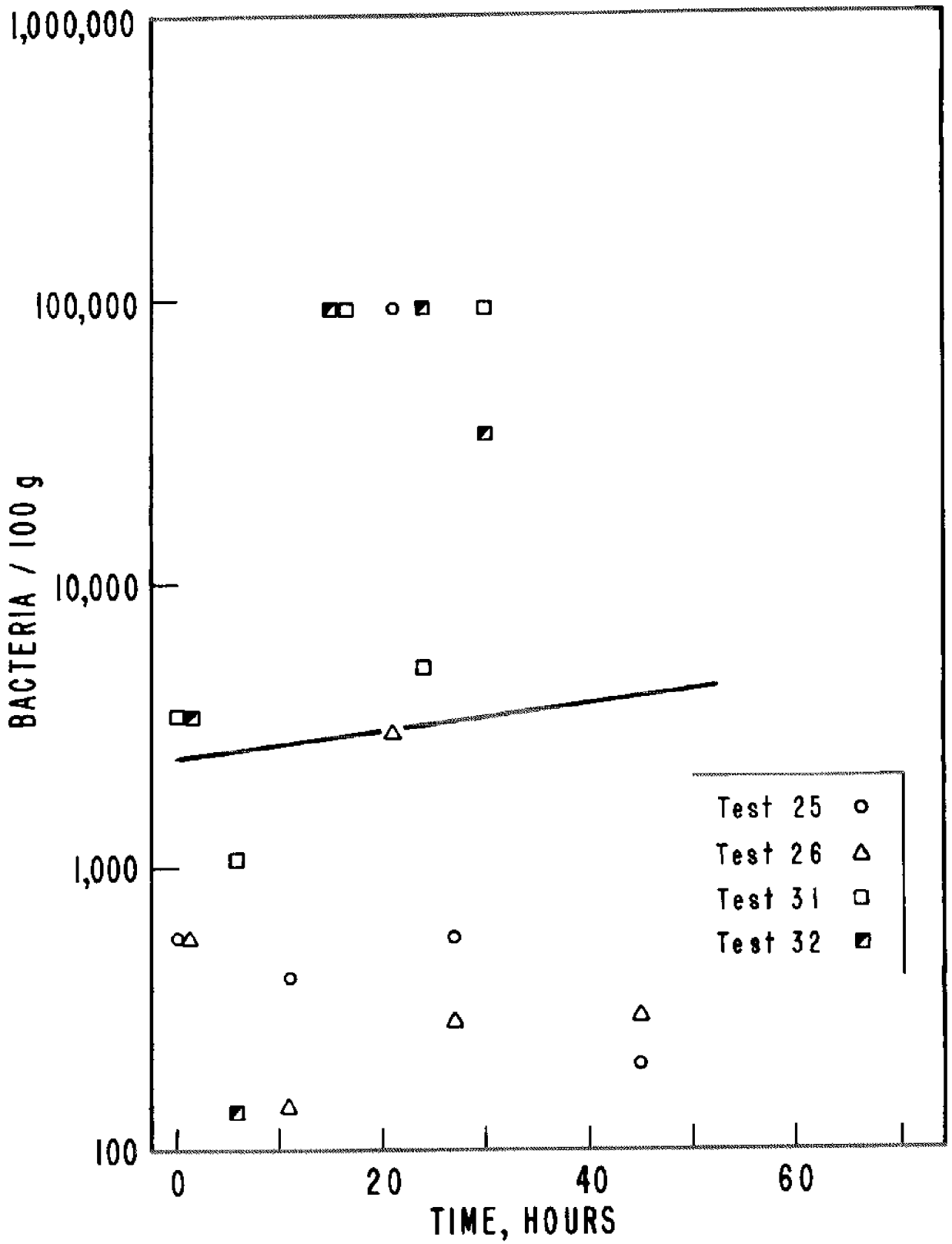
Total coliform count as a function of time for clams harvested during Spring 1973 and held at a constant temperature of 40°F.



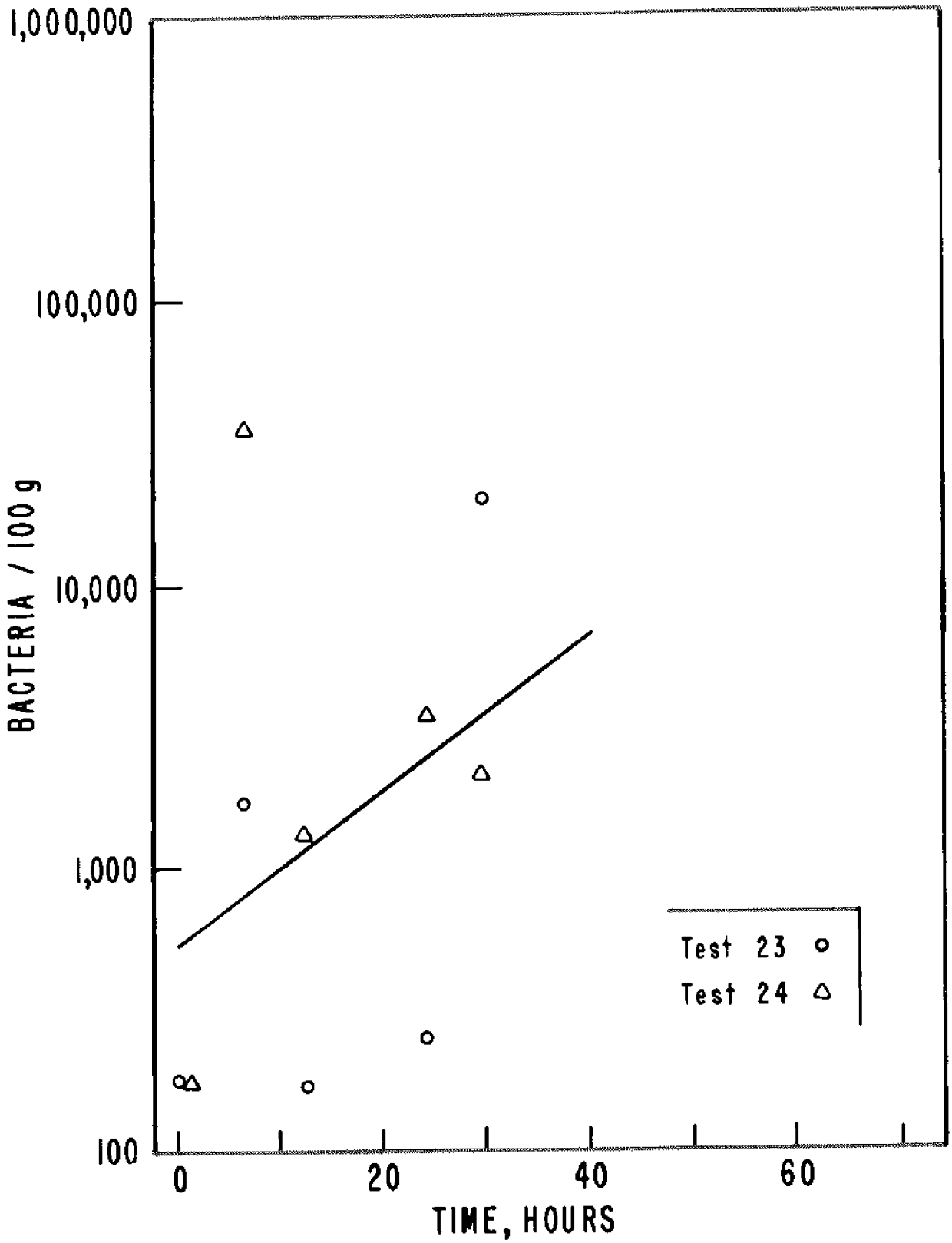
Total coliform count as a function of time for clams harvested during Spring 1973 and held at a constant temperature of 50°F.



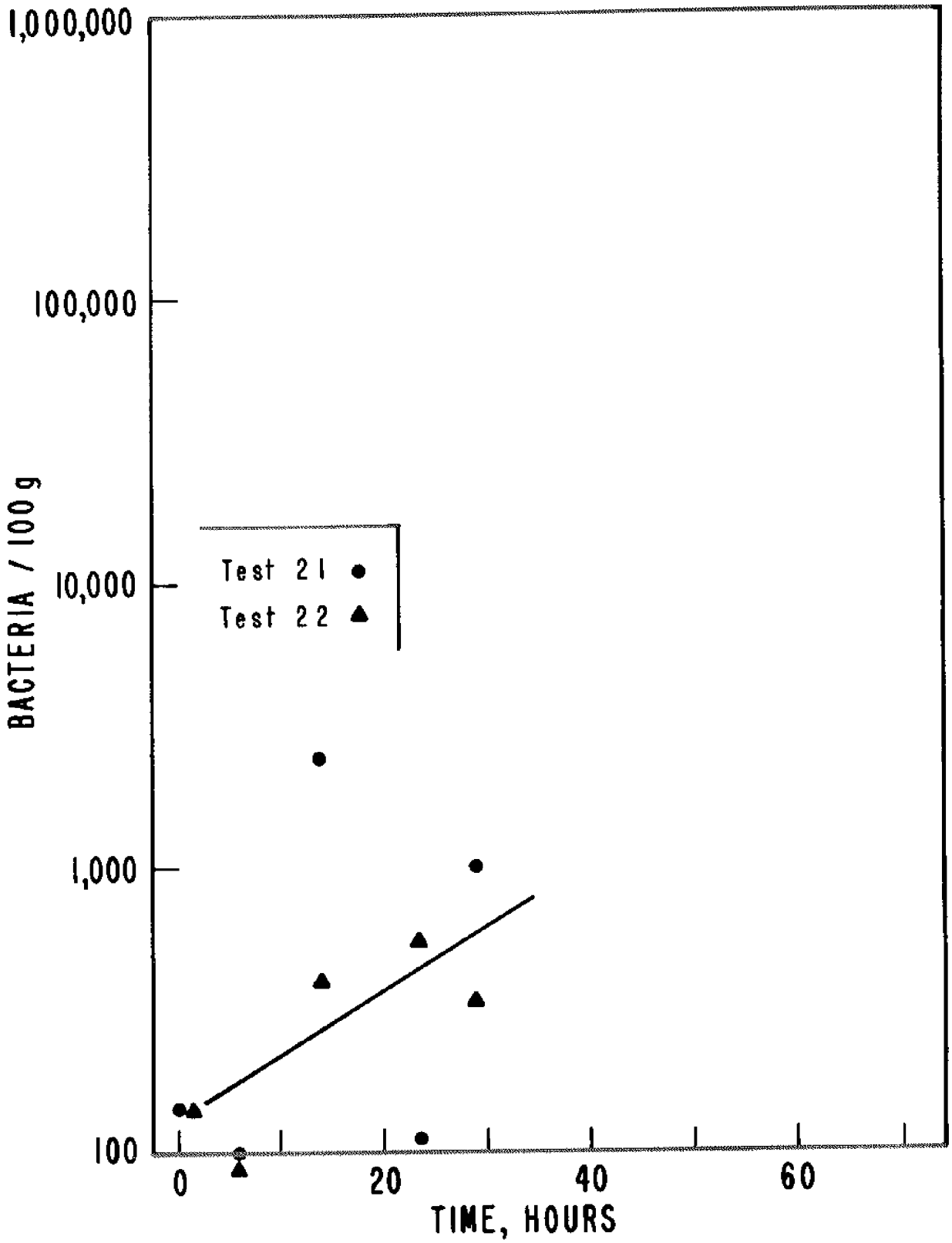
Total coliform count as a function of time for clams harvested during Spring 1973 and held at a constant temperature of 60°F.



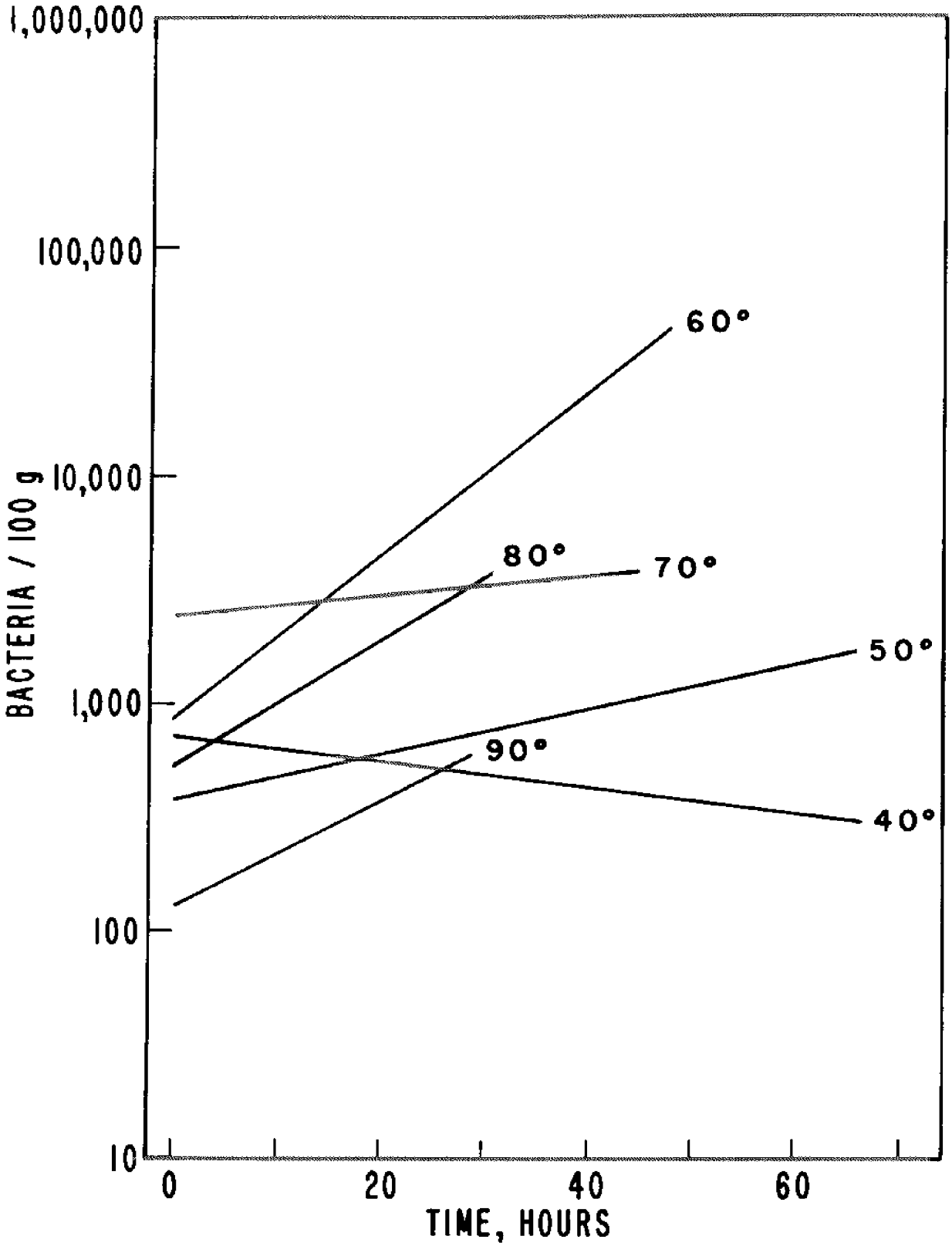
Total coliform count as a function of time for clams harvested during Spring 1973 and held at a constant temperature of 70°F.



Total coliform count as a function of time for clams harvested during Spring 1973 and held at a constant temperature of 80°F.



Total coliform count as a function of time for clams harvested during Spring 1973 and held at a constant temperature of 90°F.



Summary of total coliform counts as a function of time for clams harvested during Spring 1973 and held at the indicated temperatures.

Appendix A-2

Winter 1973-74

Plate Counts at
40, 50, 60, 70, 80, 90°F

Total Coliform Count at
40, 50, 60, 70, 80, 90°F

Fecal Coliform Counts at
40, 50, 60, 70, 80, 90°F

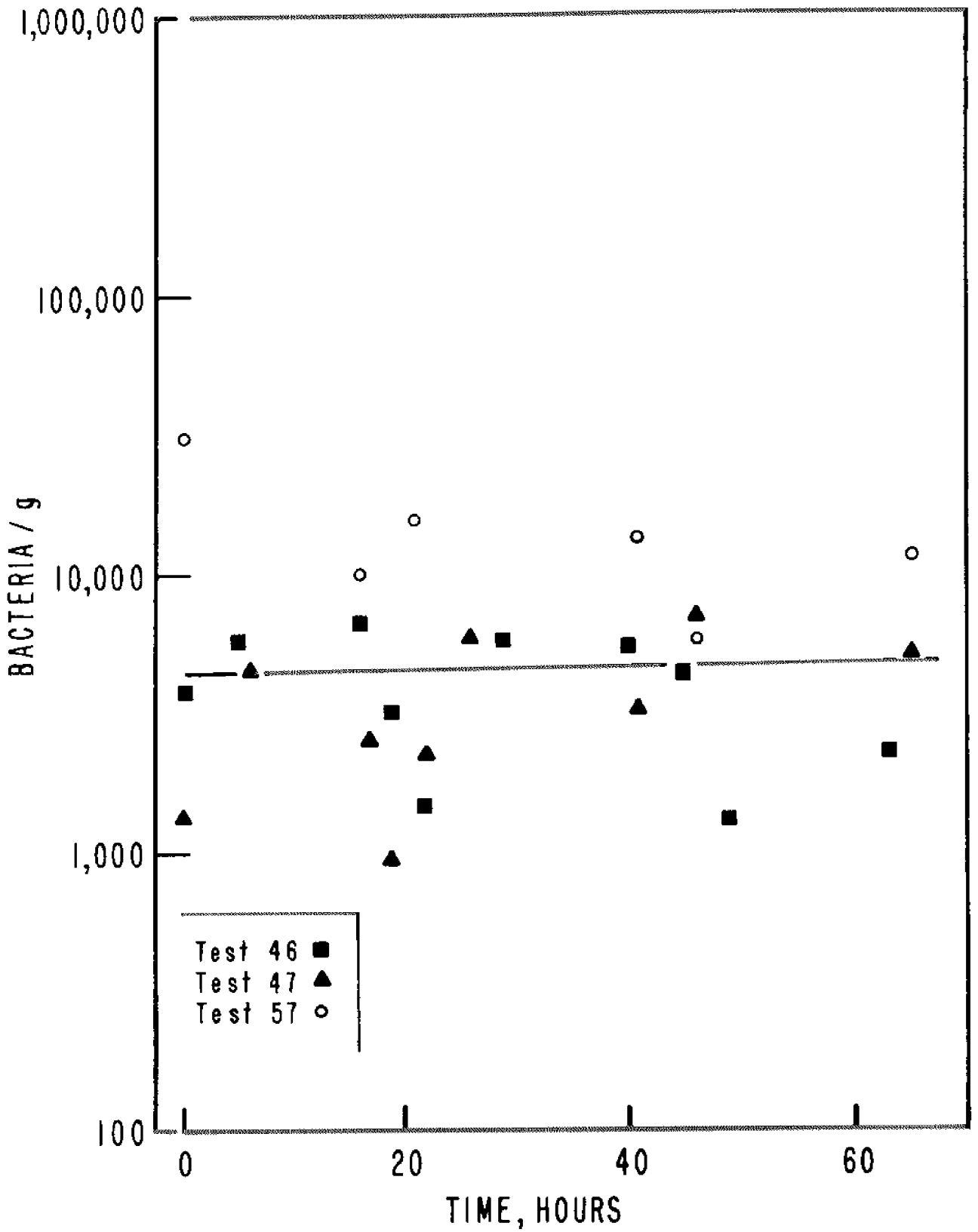


Plate count as a function of time for clams harvested during Winter 1973-74 and held at a constant temperature of 40°F.

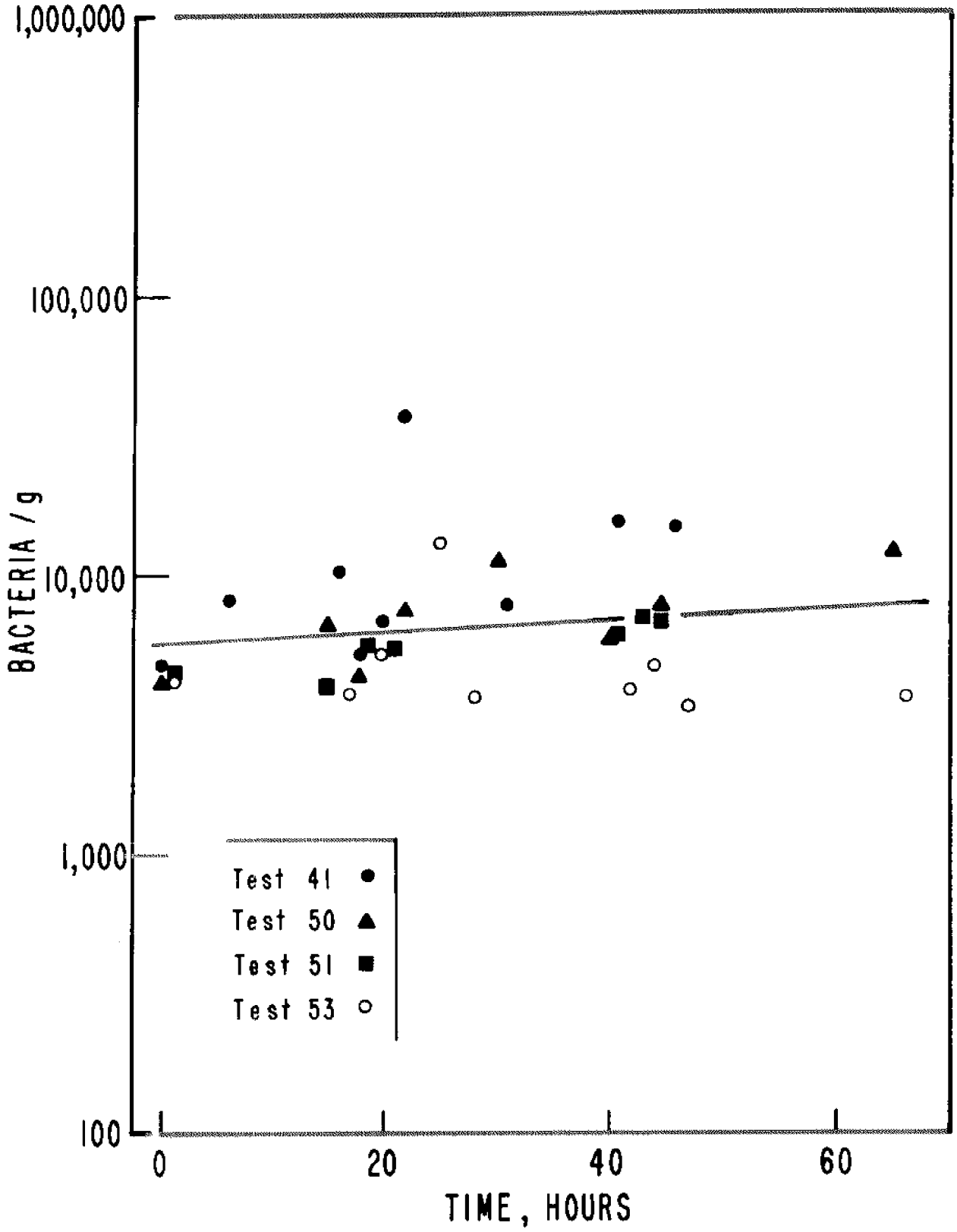


Plate count as a function of time for clams harvested during Winter 1973-74 and held at a constant temperature of 50°F.

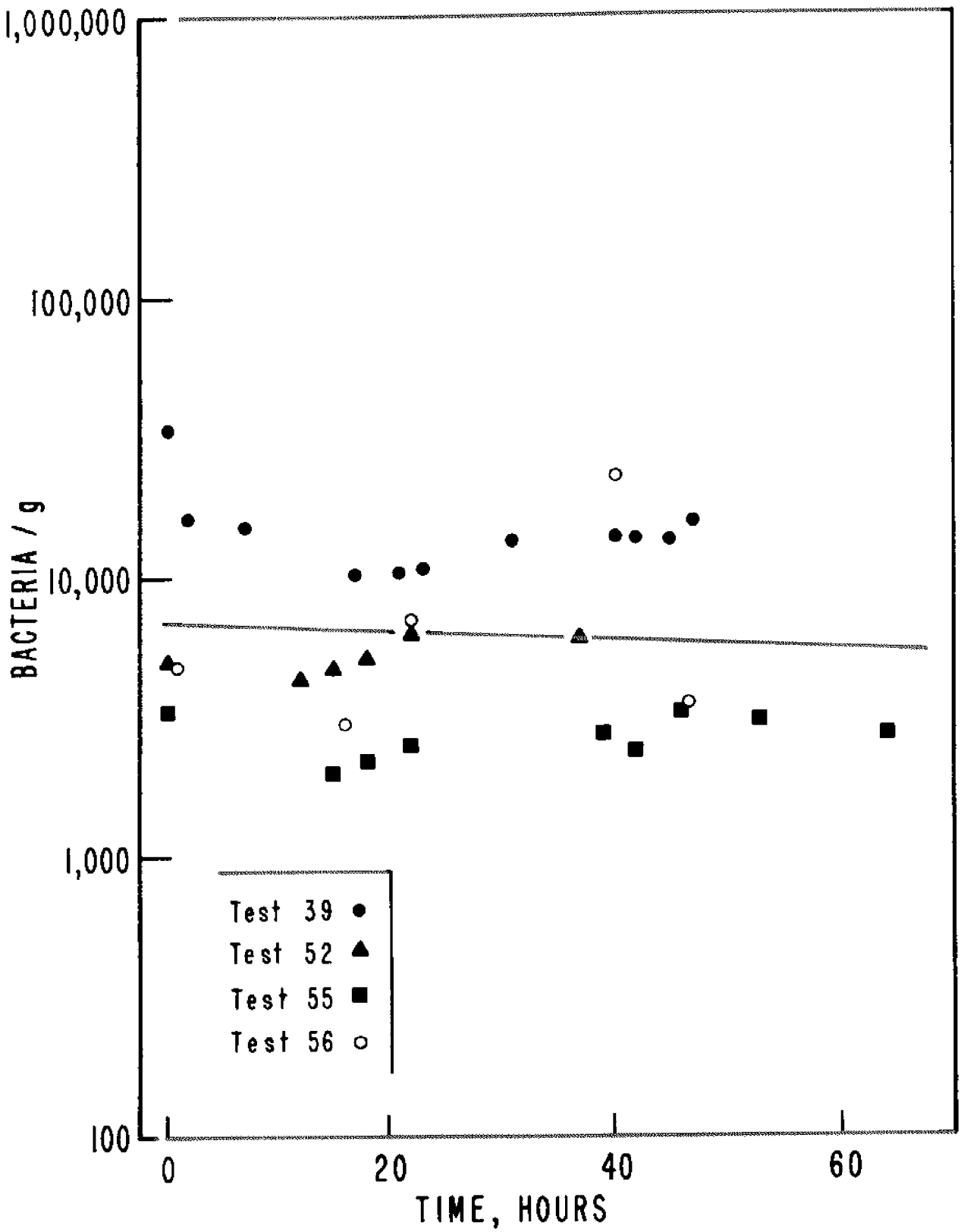


Plate count as a function of time for clams harvested during Winter 1973-74 and held at a constant temperature of 60°F.

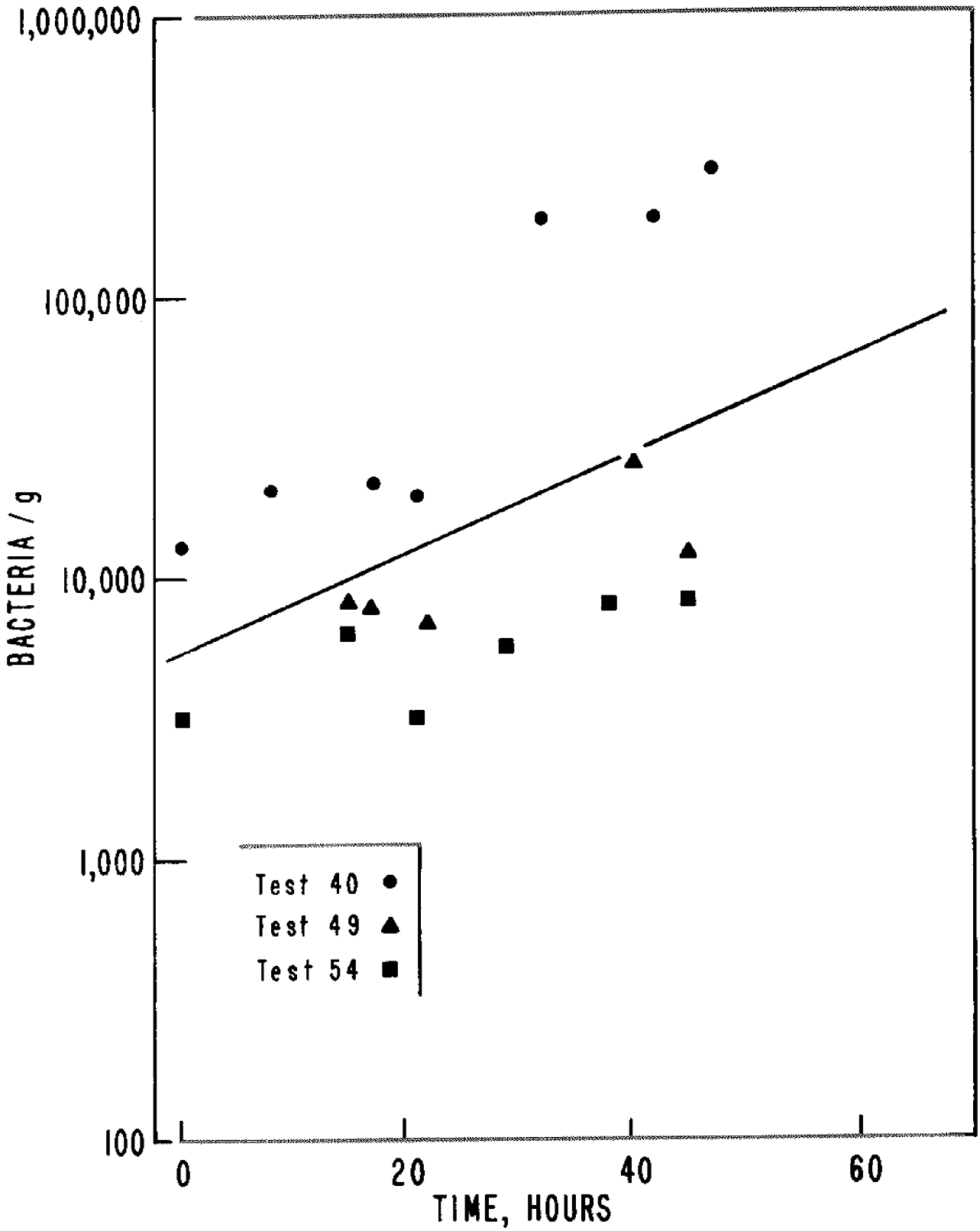


Plate count as a function of time for clams harvested during Winter 1973-74 and held at a constant temperature of 70°F.

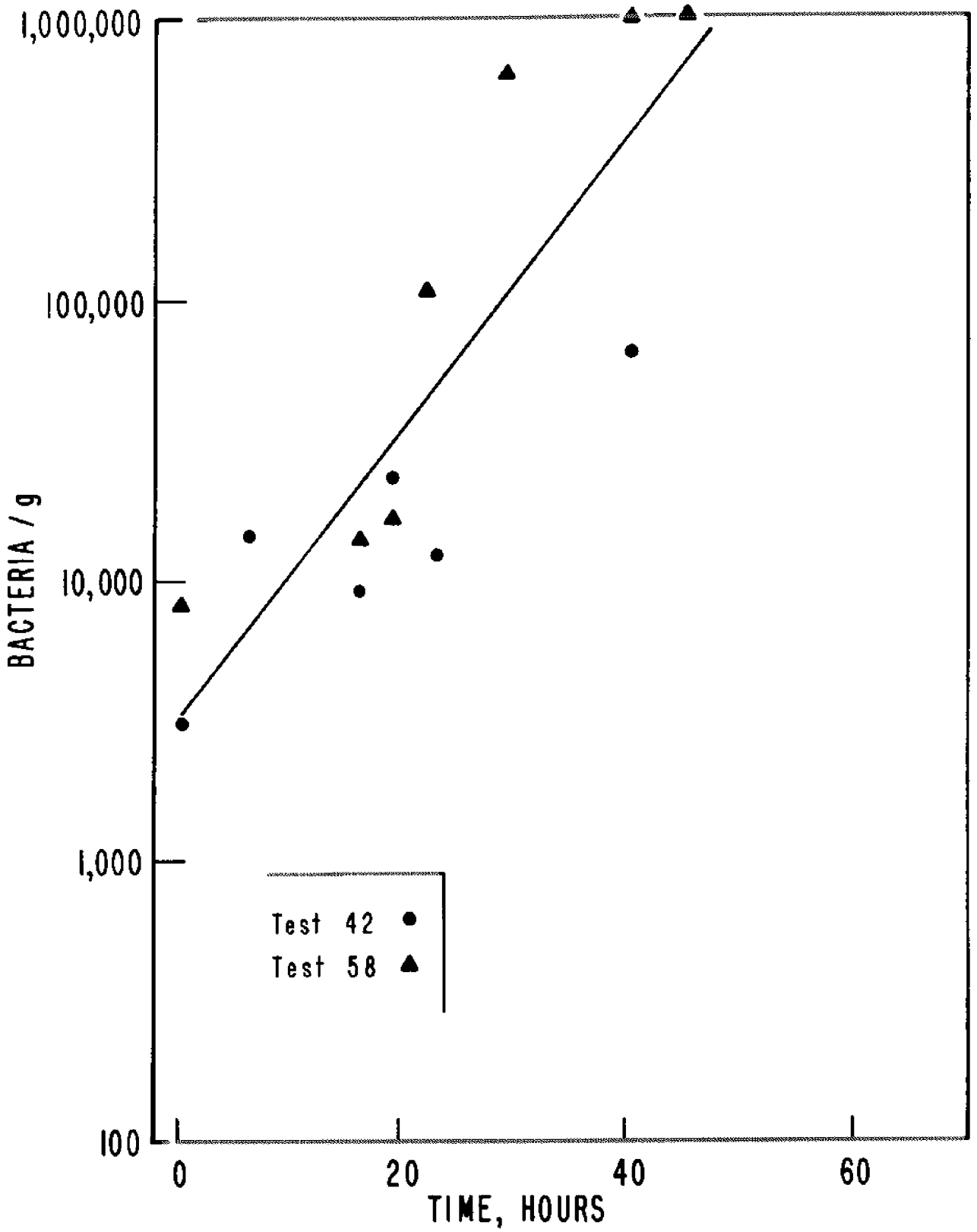


Plate count as a function of time for clams harvested during Winter 1973-74 and held at a constant temperature of 80°F.

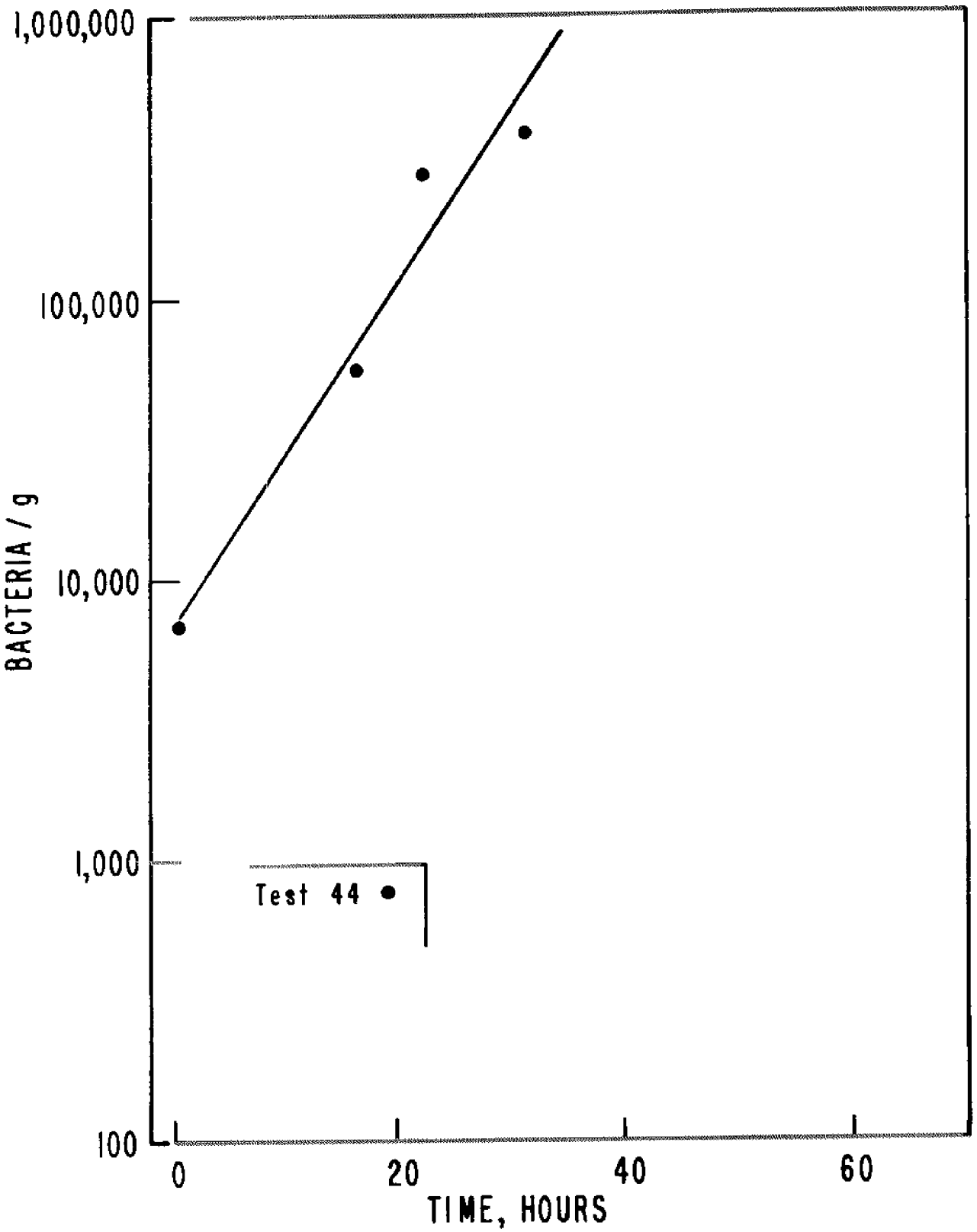
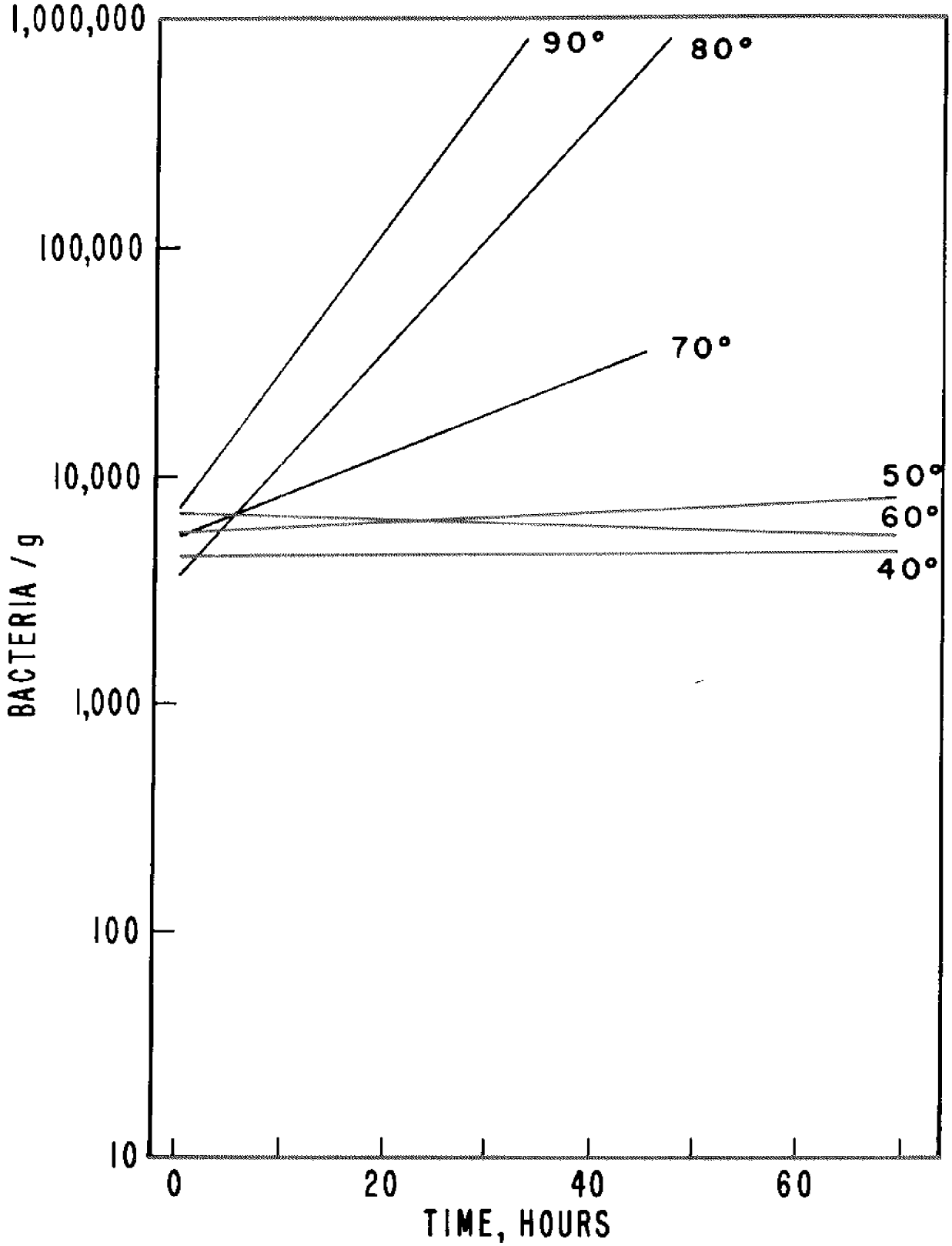
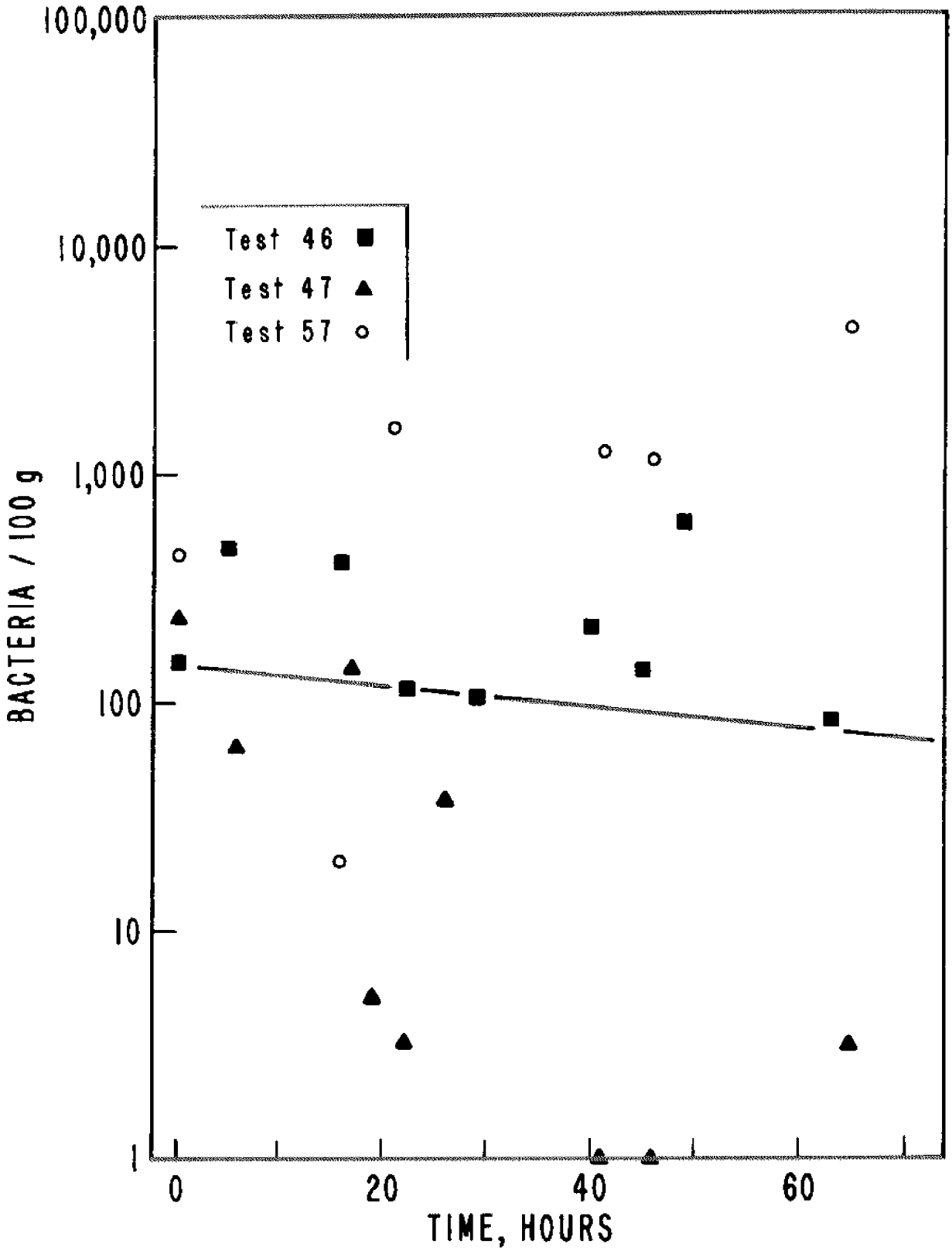


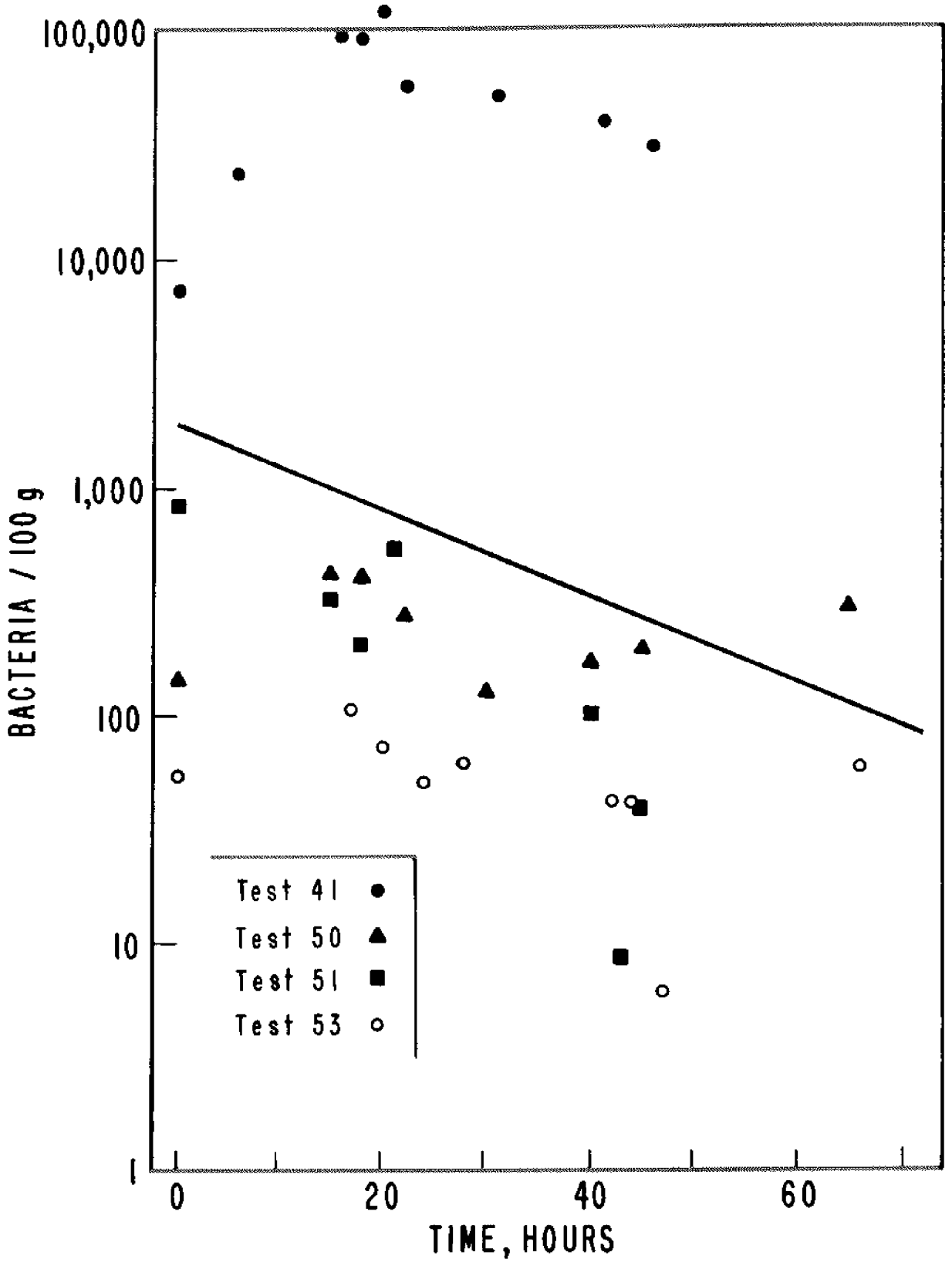
Plate count as a function of time for clams harvested during Winter 1973-74 and held at a constant temperature of 90°F.



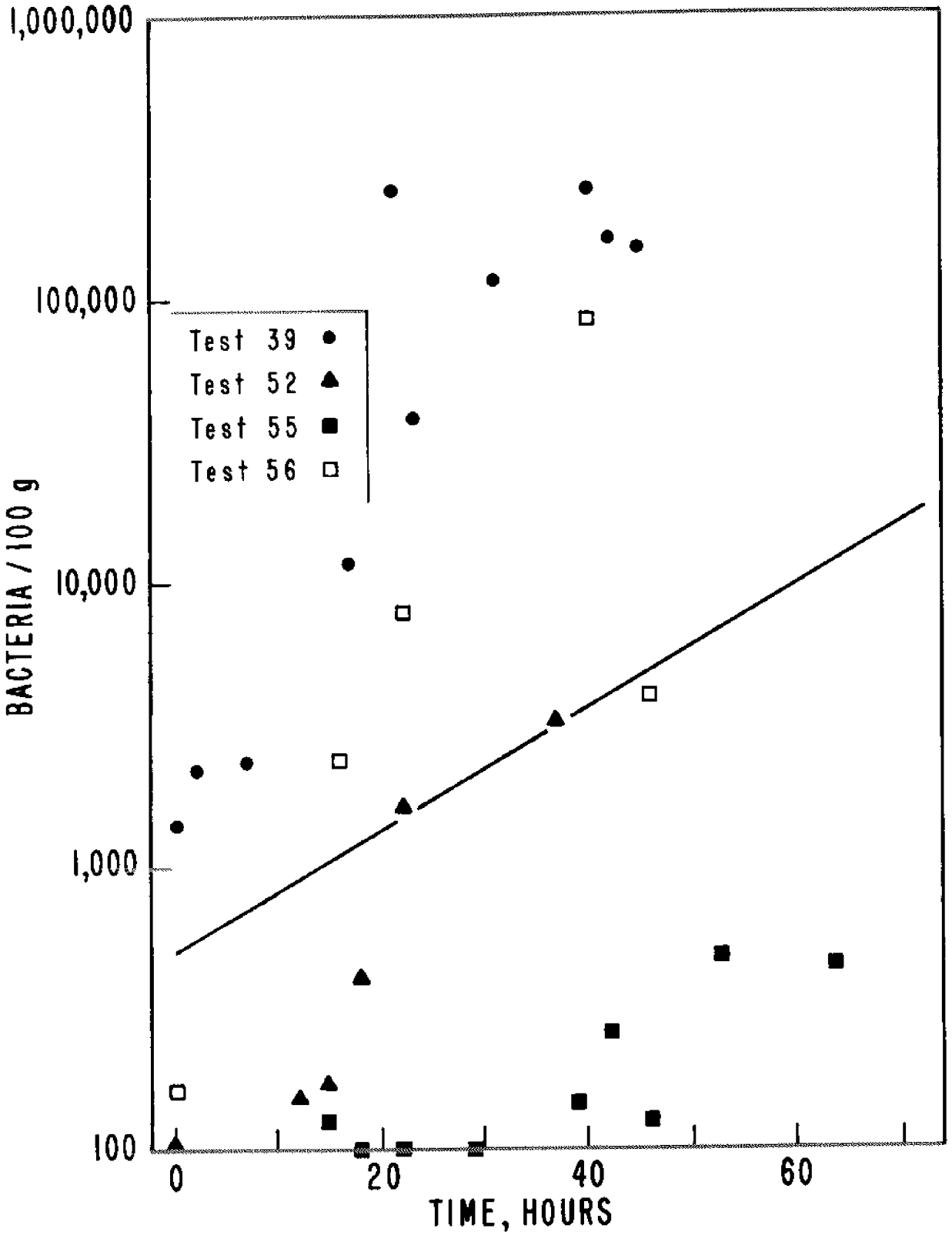
Summary of plate counts as a function of time for clams harvested during Winter 1973-74 and held at the indicated temperatures.



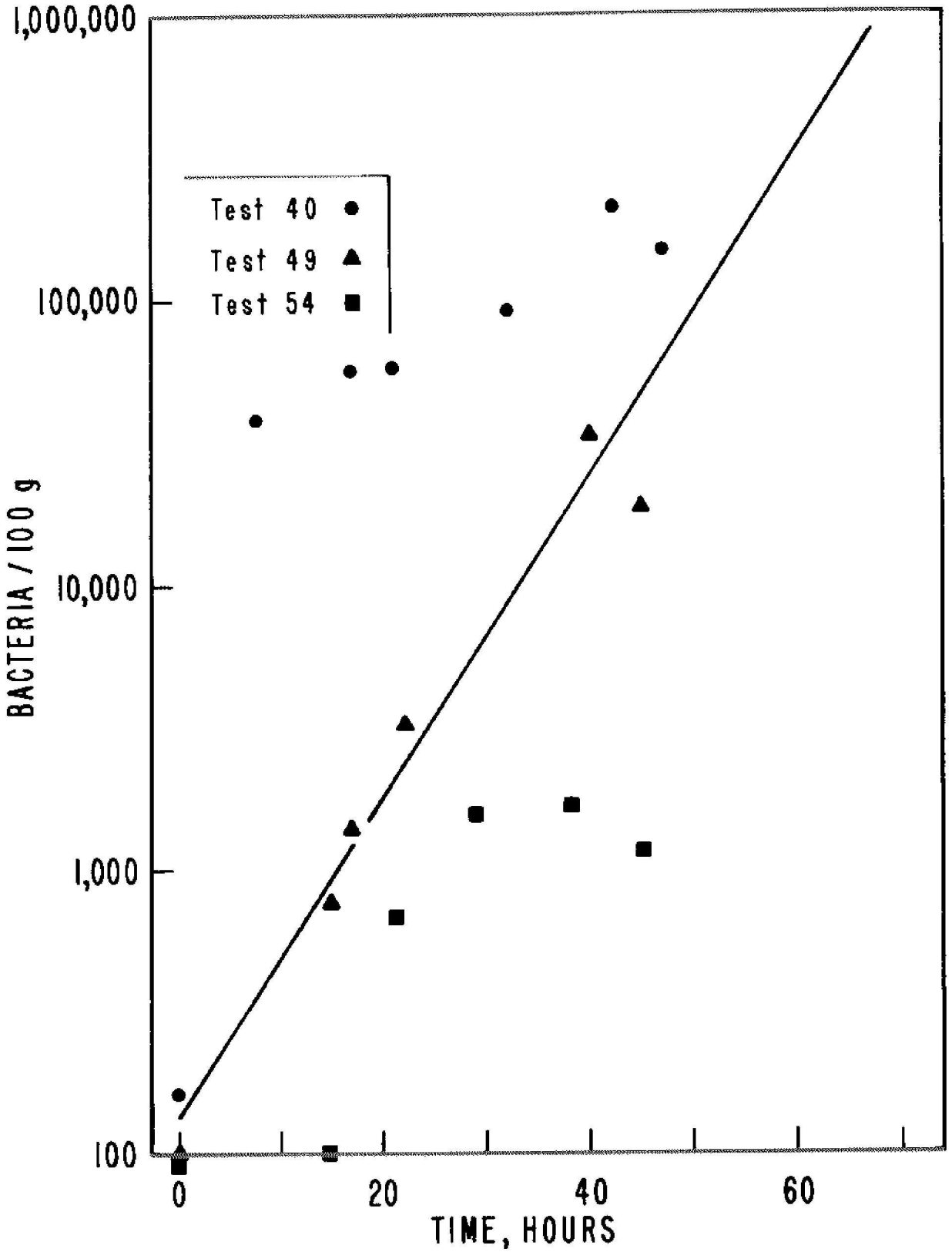
Total coliform count as a function of time for clams harvested during Winter 1973-74 and held at a constant temperature of 40°F.



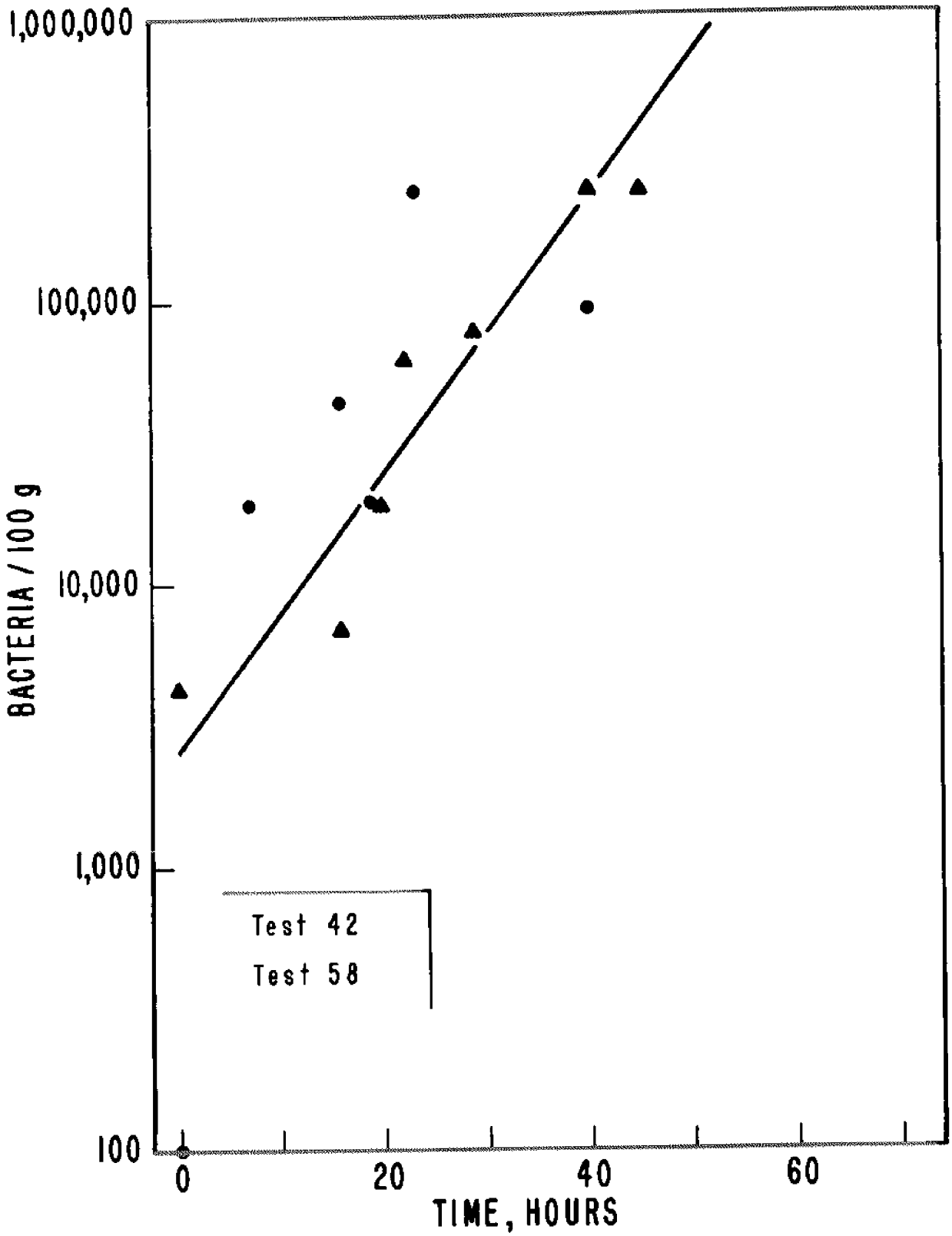
Total coliform count as a function of time for clams harvested during Winter 1973-74 and held at a constant temperature of 50°F.



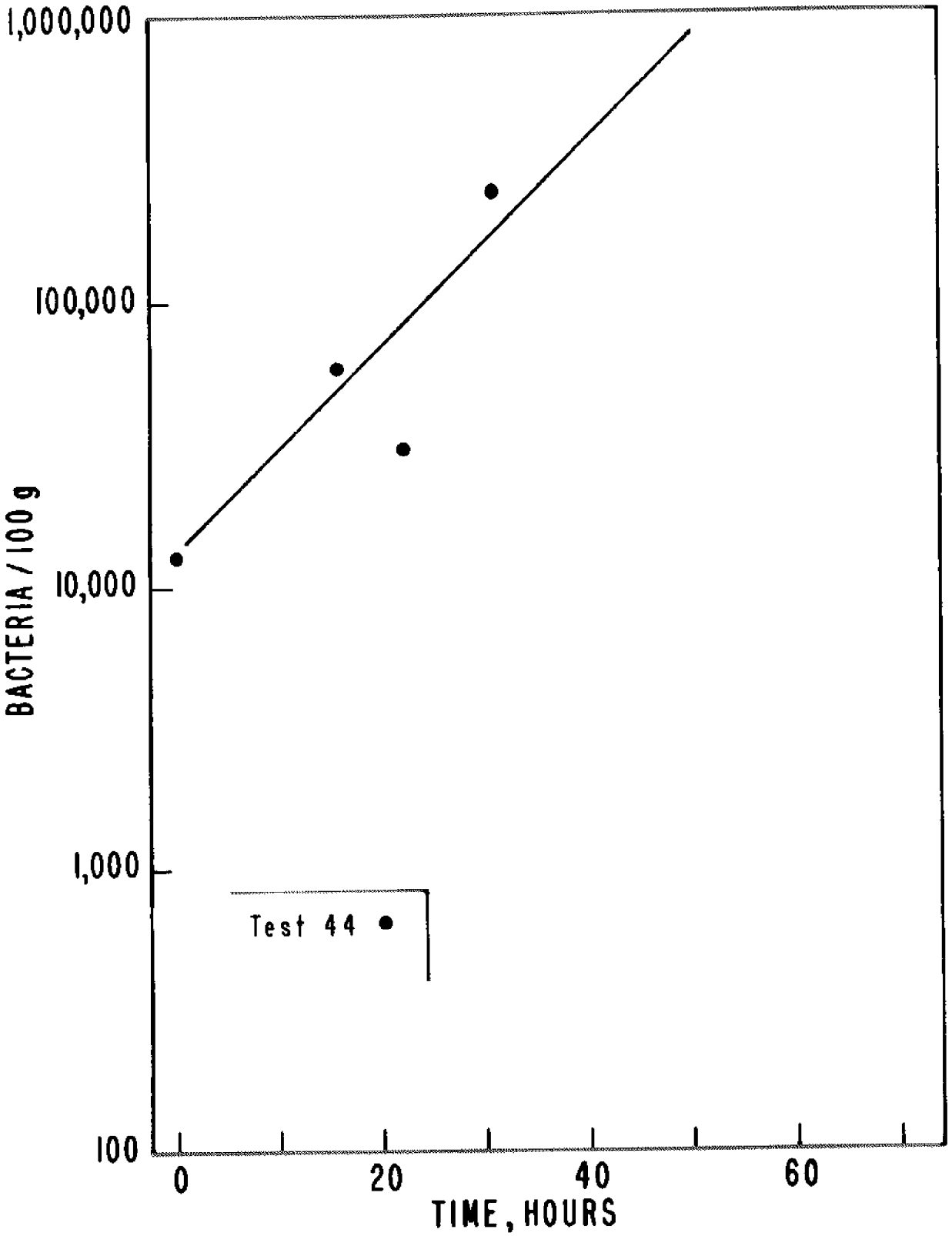
Total coliform count as a function of time for clams harvested during Winter 1973-74 and held at a constant temperature of 60°F.



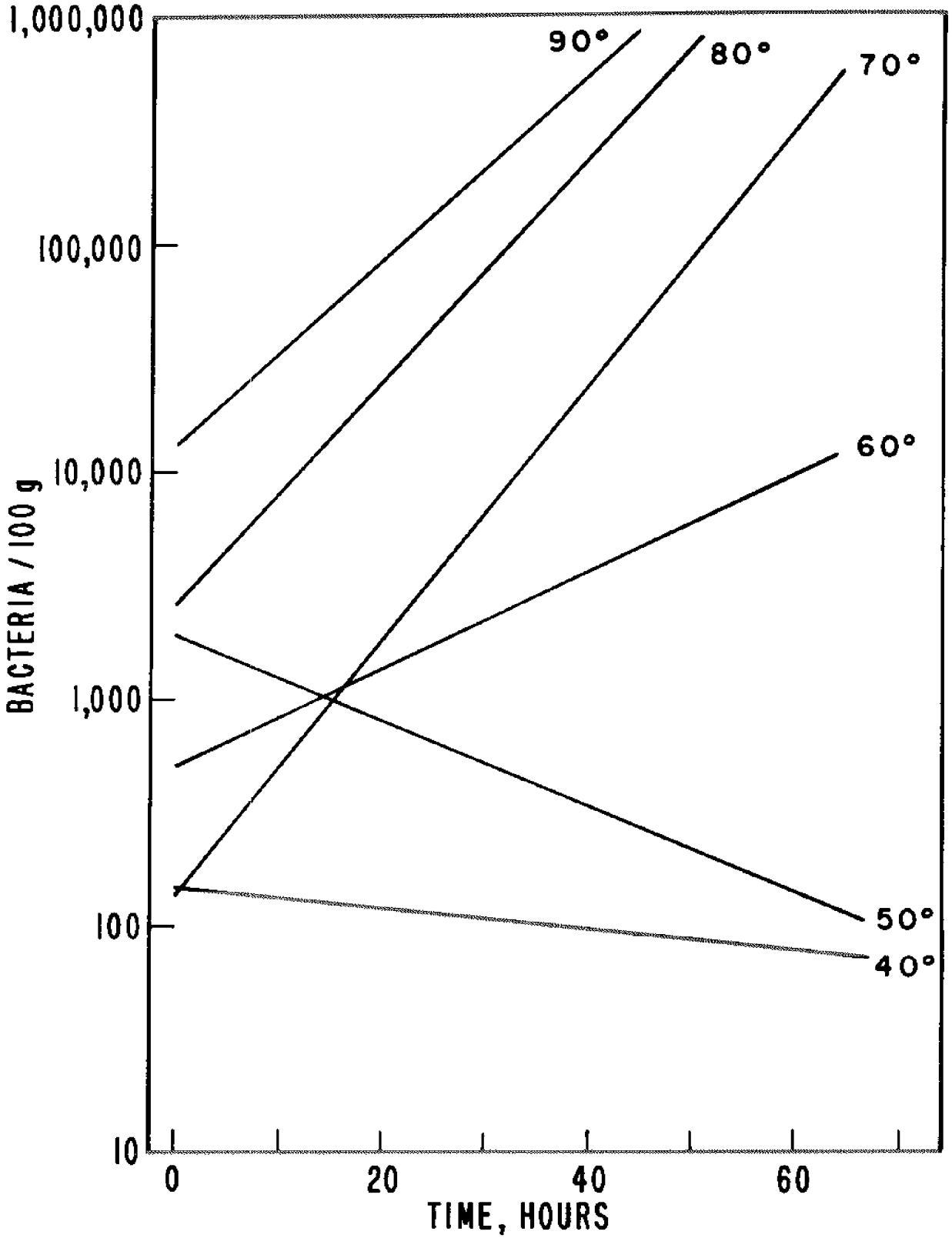
Total coliform count as a function of time for clams harvested during Winter 1973-74 and held at a constant temperature of 70°F.



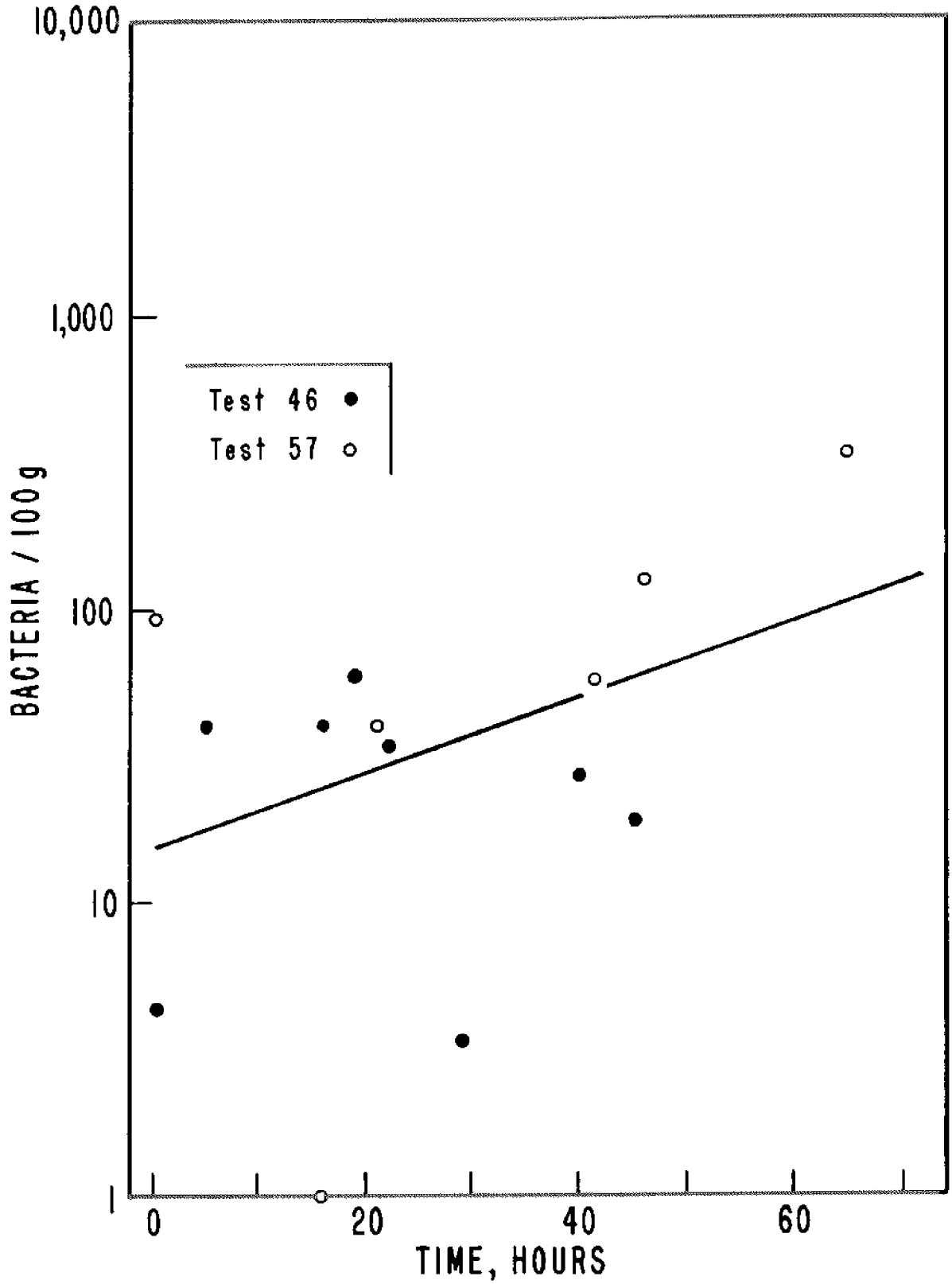
Total coliform count as a function of time for clams harvested during Winter 1973-74 and held at a constant temperature of 80°F.



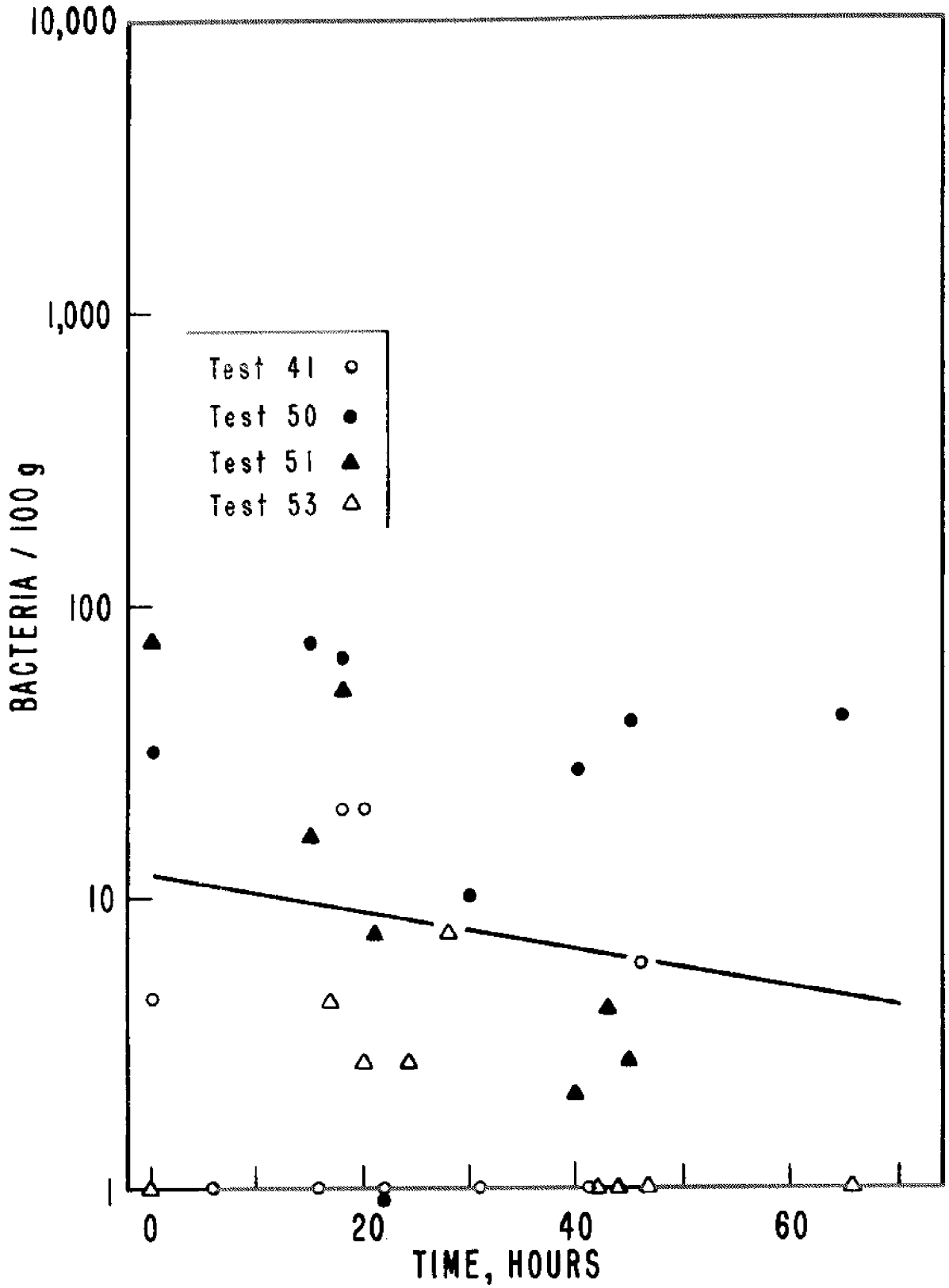
Total coliform count as a function of time for clams harvested during Winter 1973-74 and held at a constant temperature of 90°F.



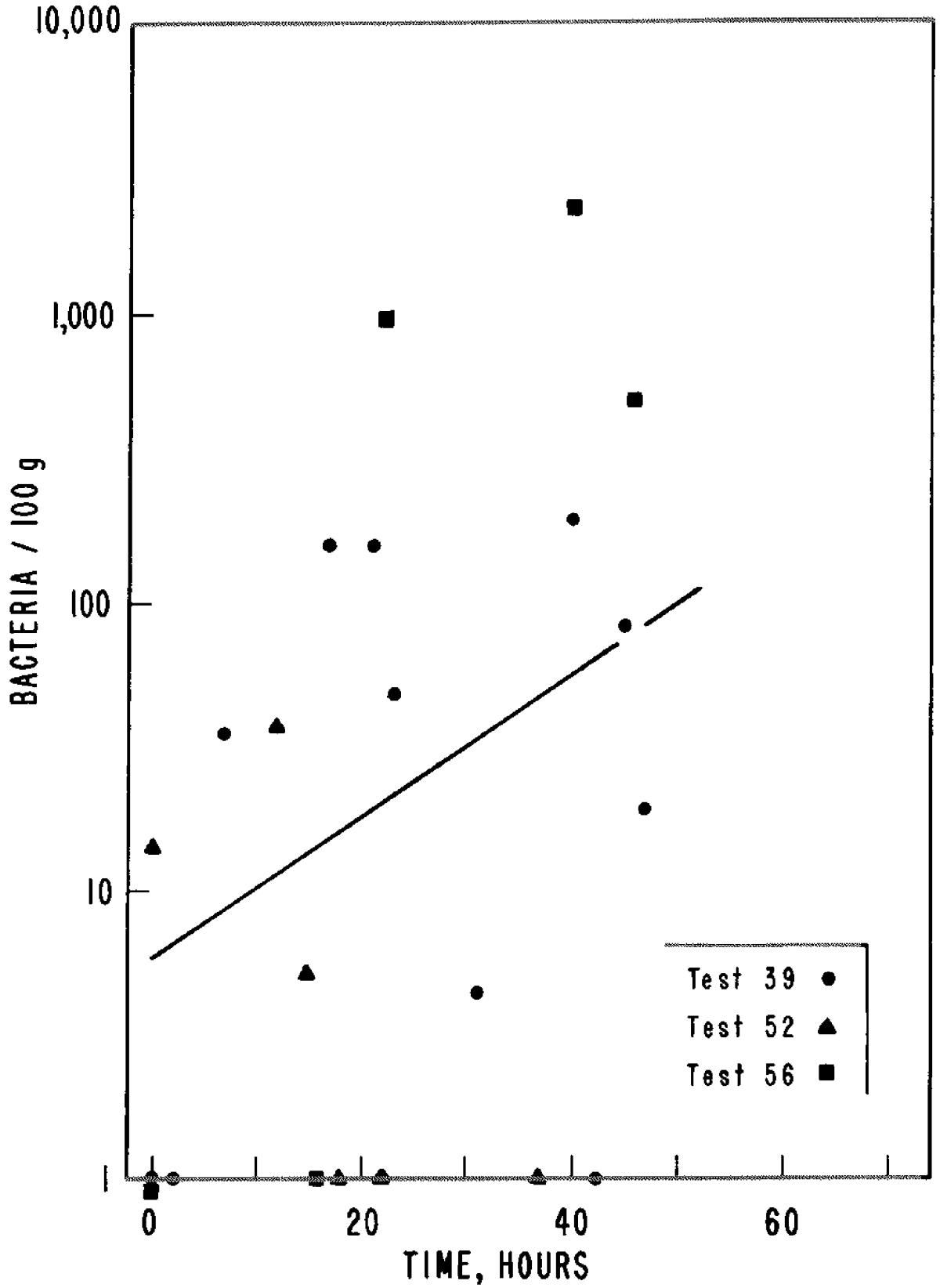
Summary of total coliform counts as a function of time for clams harvested during Winter 1973-74 and held at the indicated temperatures.



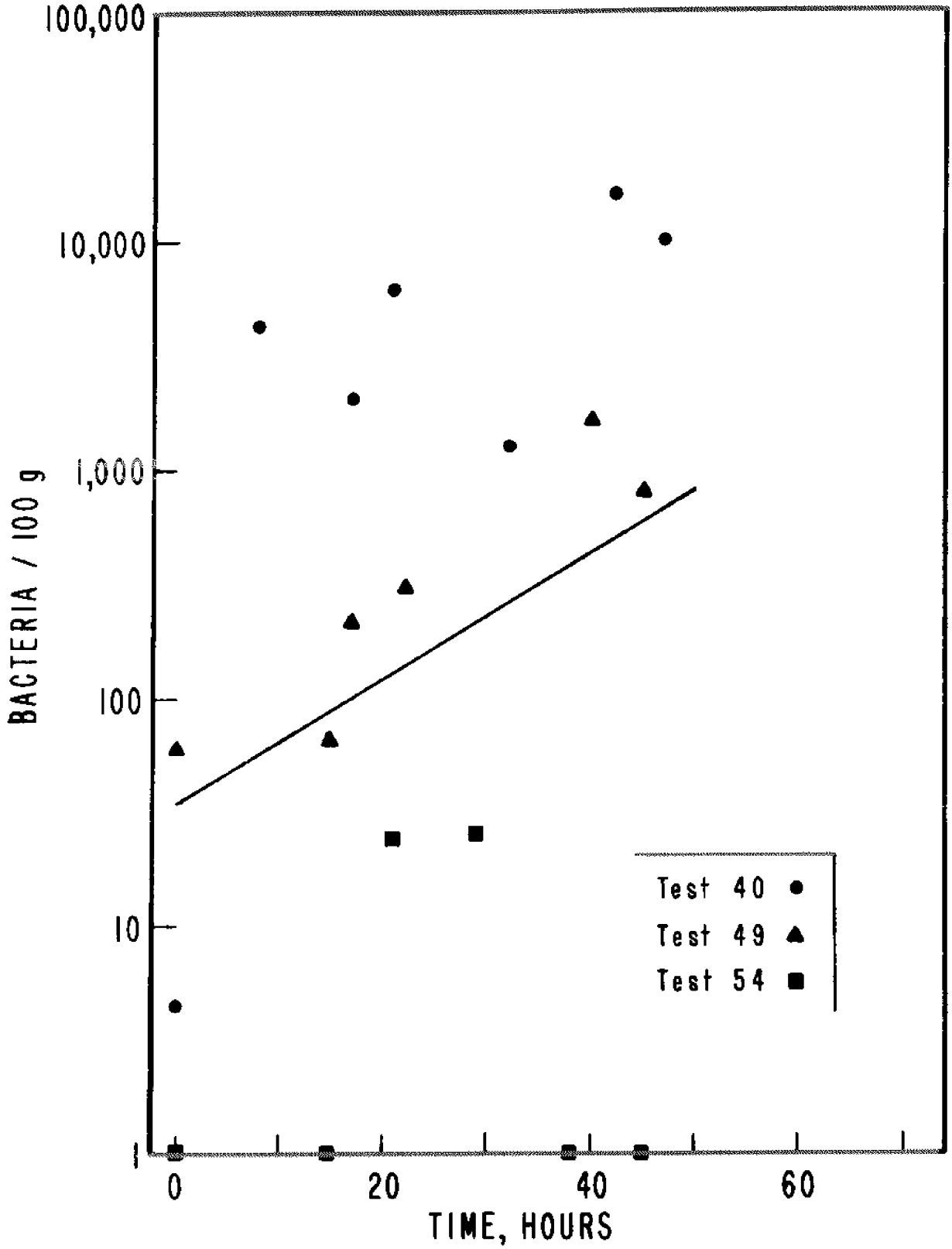
Fecal coliform count as a function of time for clams harvested during Winter 1973-74 and held at a constant temperature of 40°F.



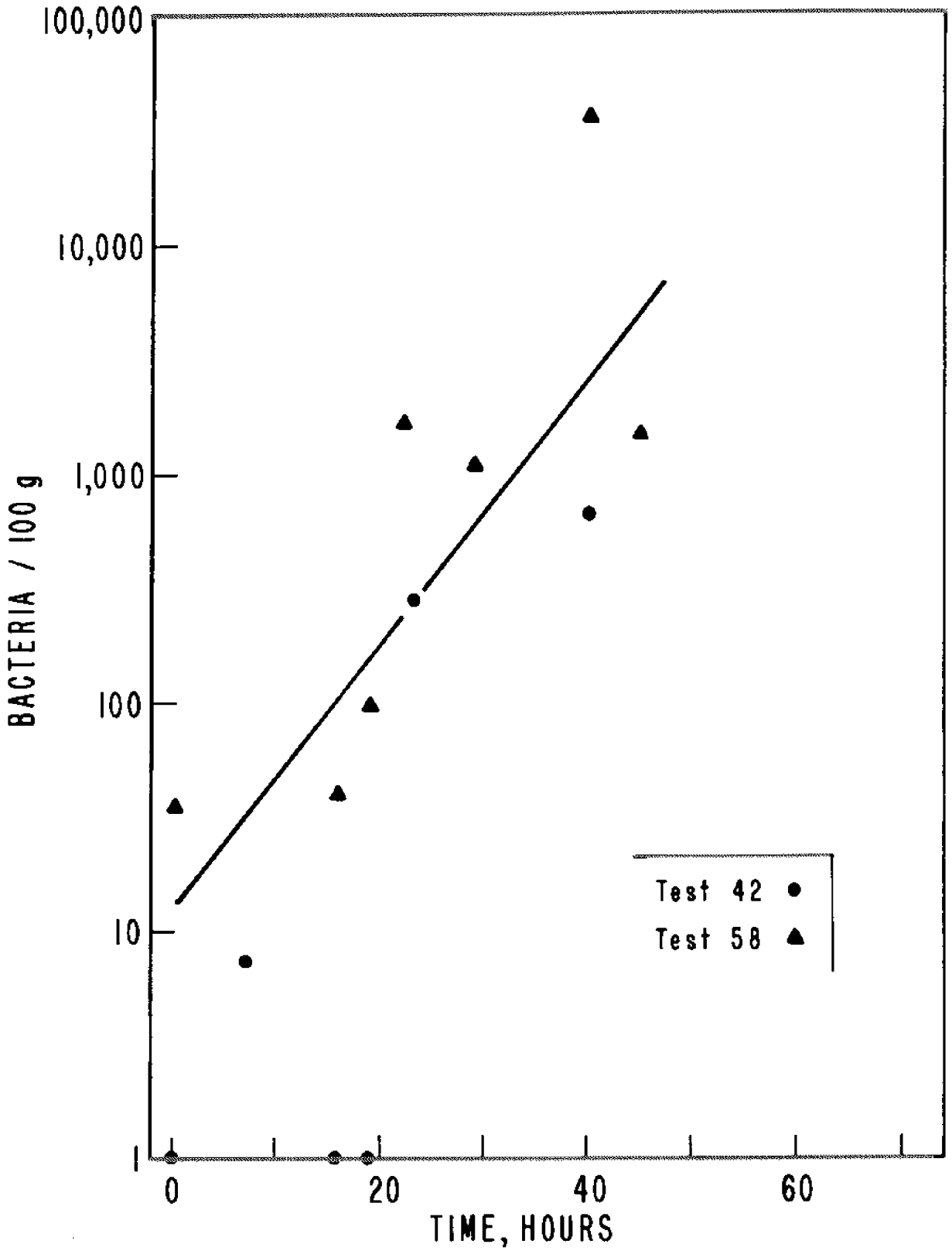
Fecal coliform count as a function of time for clams harvested during Winter 1973-74 and held at a constant temperature of 50°F.



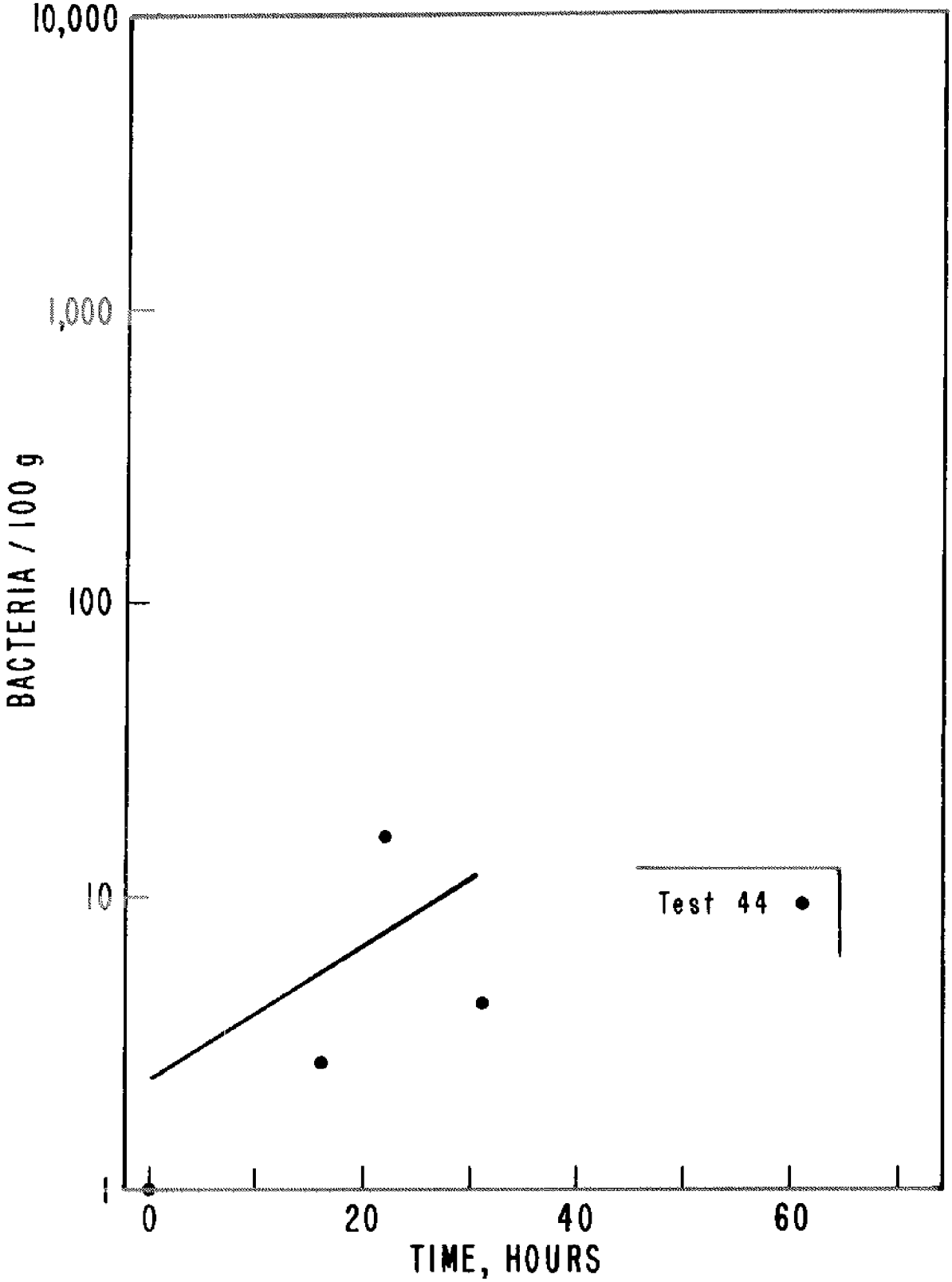
Fecal coliform count as a function of time for clams harvested during Winter 1973-74 and held at a constant temperature of 60°F.



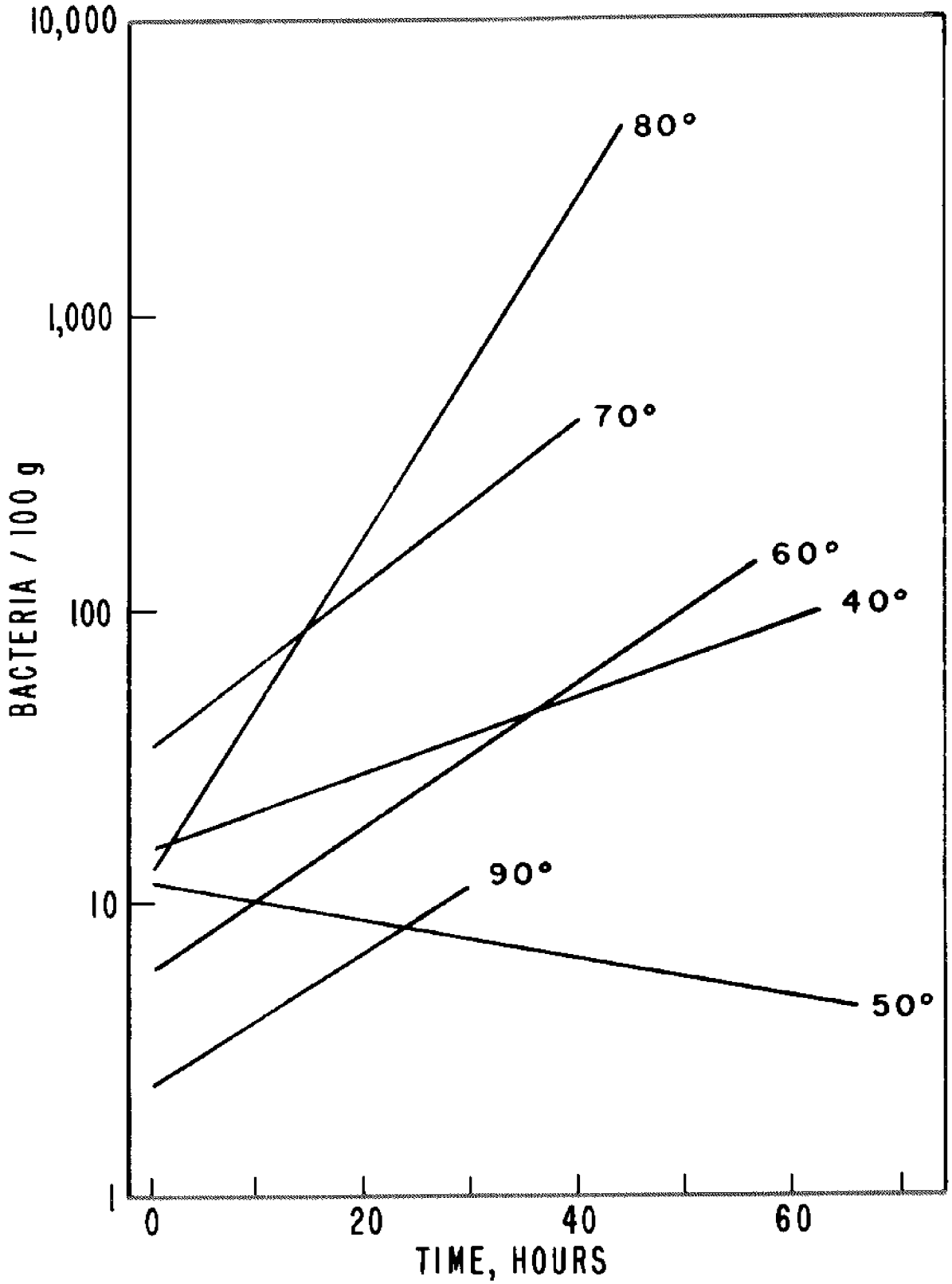
Fecal coliform count as a function of time for clams harvested during Winter 1973-74 and held at a constant temperature of 70°F.



Fecal coliform count as a function of time for clams harvested during Winter 1973-74 and held at a constant temperature of 80°F.



Fecal coliform count as a function of time for clams harvested during Winter 1973-74 and held at a constant temperature of 90°F.



Summary of fecal coliform counts as a function of time for clams harvested during Winter 1973-74 and held at the indicated temperatures.

Appendix A-3

Summer 1974

Plate Counts at
40, 50, 60, 70°F

Total Coliform Counts at
40, 50, 60, 70°F

Fecal Coliform Counts at
40, 50, 60, 70°F

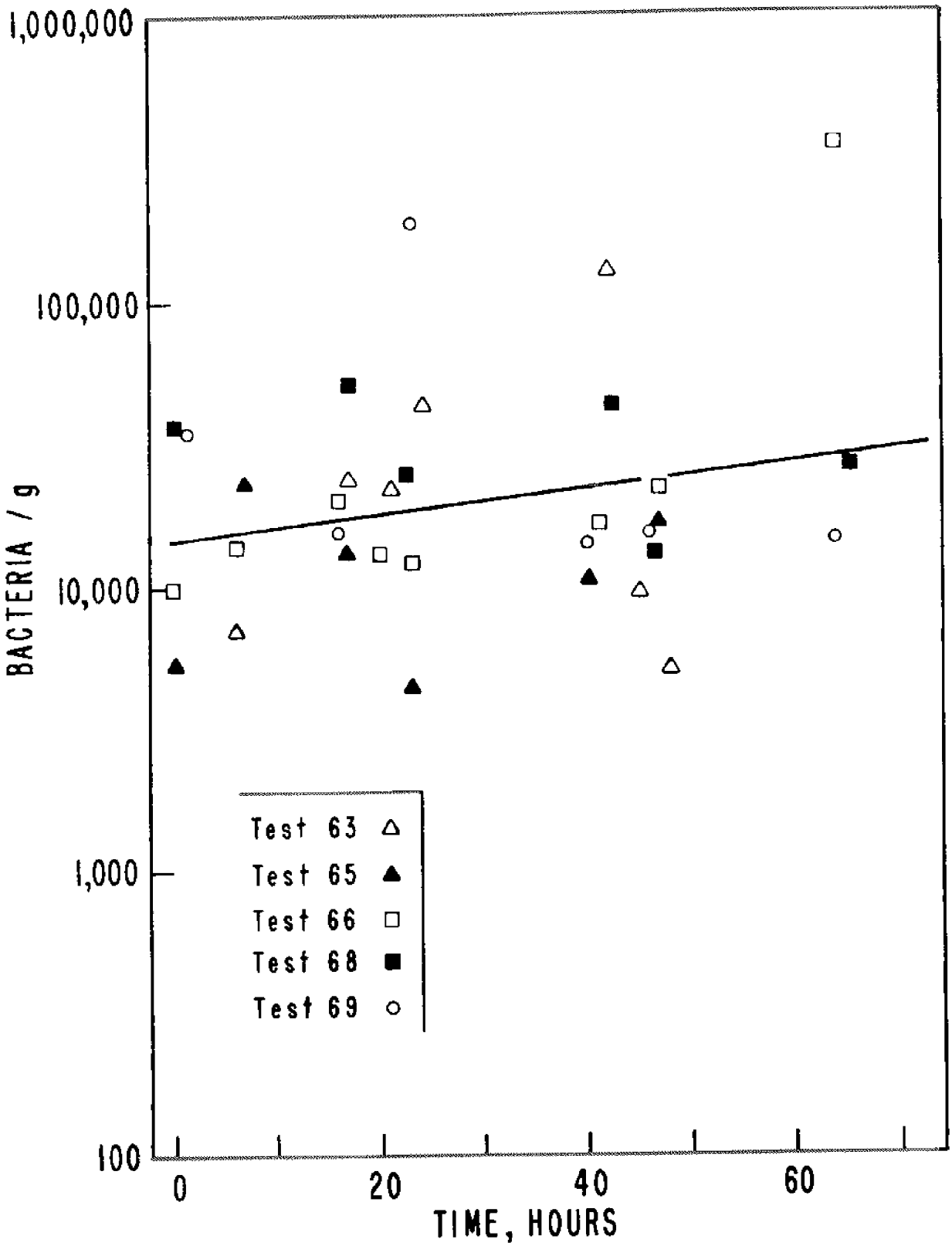


Plate count as a function of time for clams harvested during Summer 1974 and held at a constant temperature of 40°F.

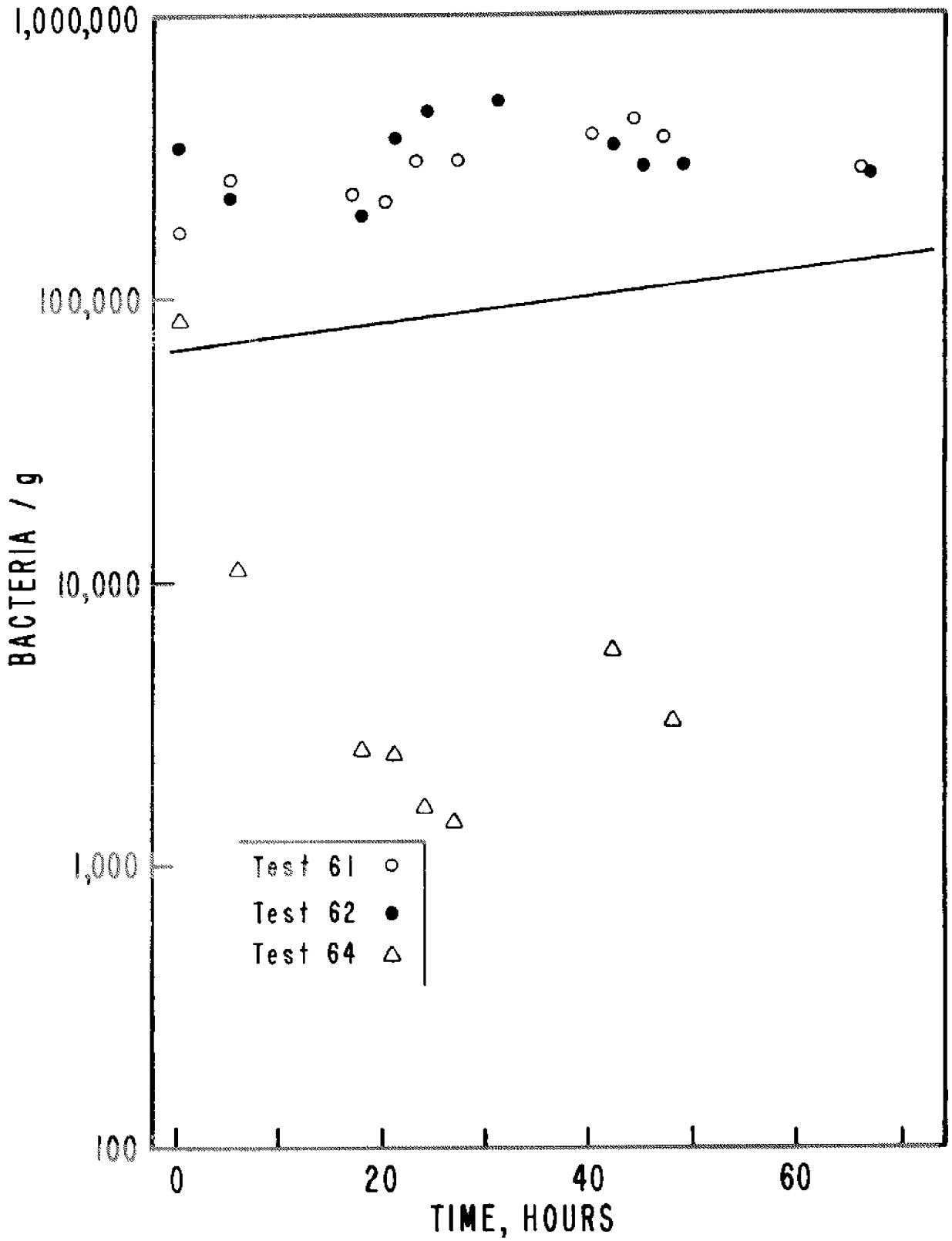


Plate count as a function of time for clams harvested during Summer 1974 and held at a constant temperature of 50°F.

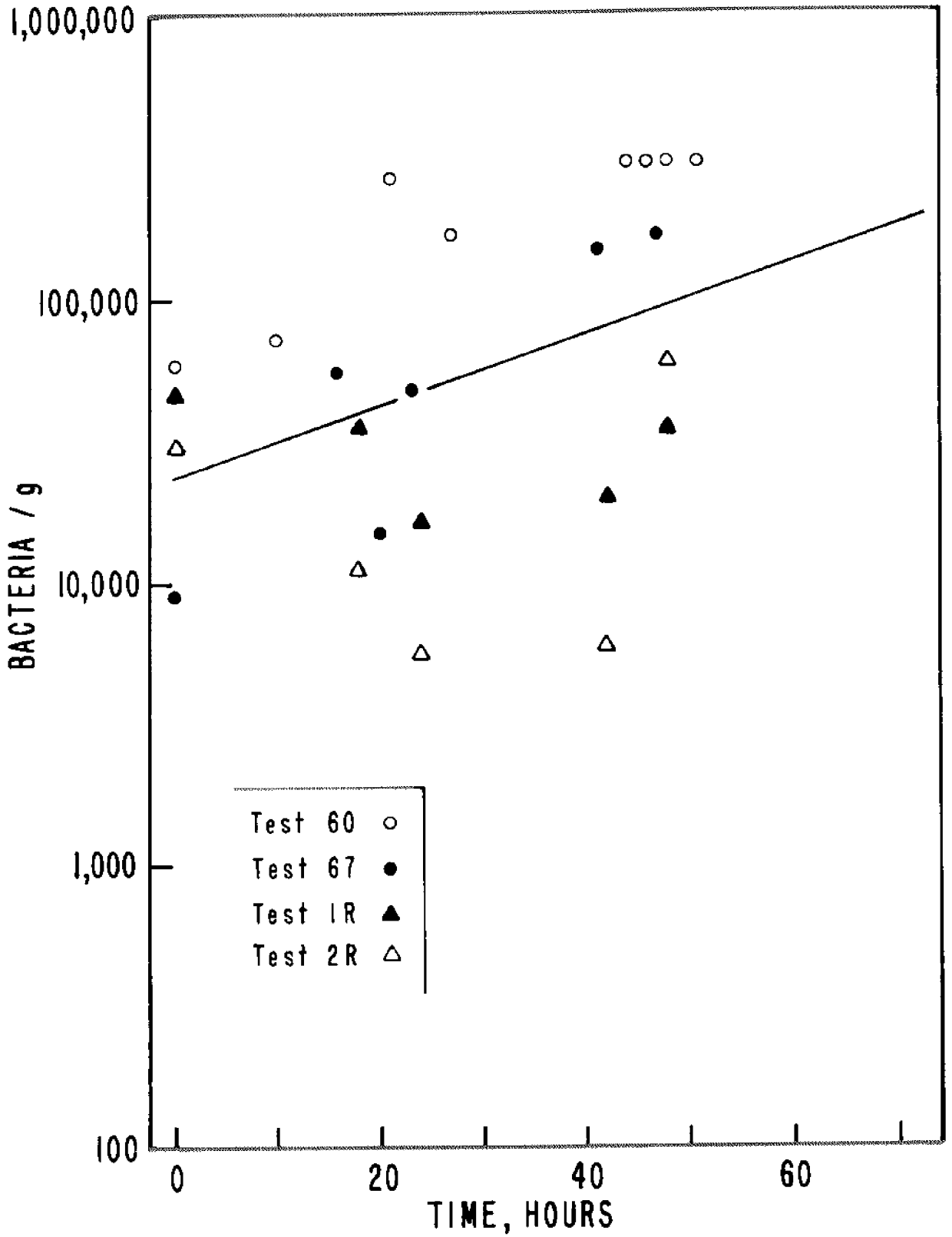


Plate count as a function of time for clams harvested during Summer 1974 and held at a constant temperature of 60°F.

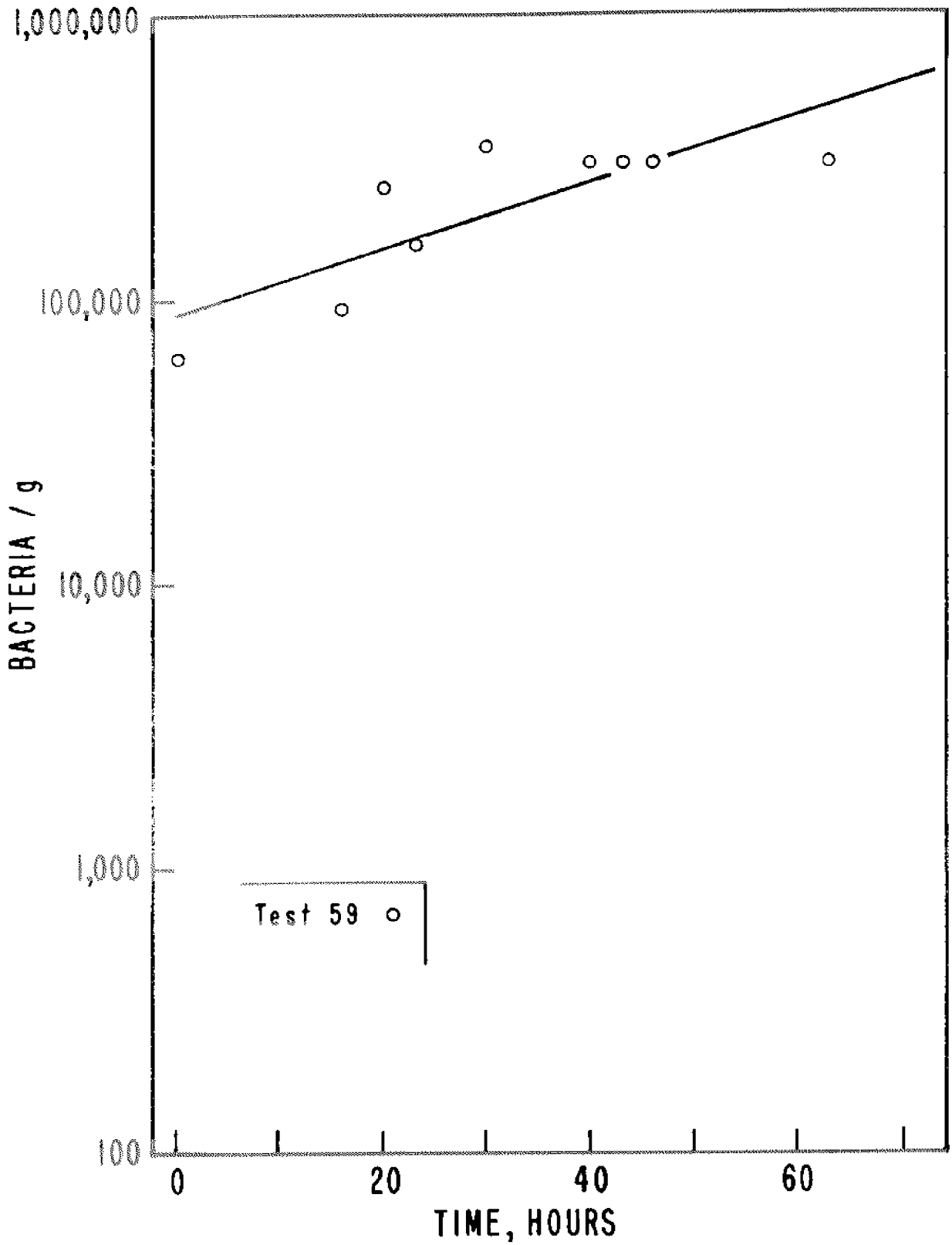
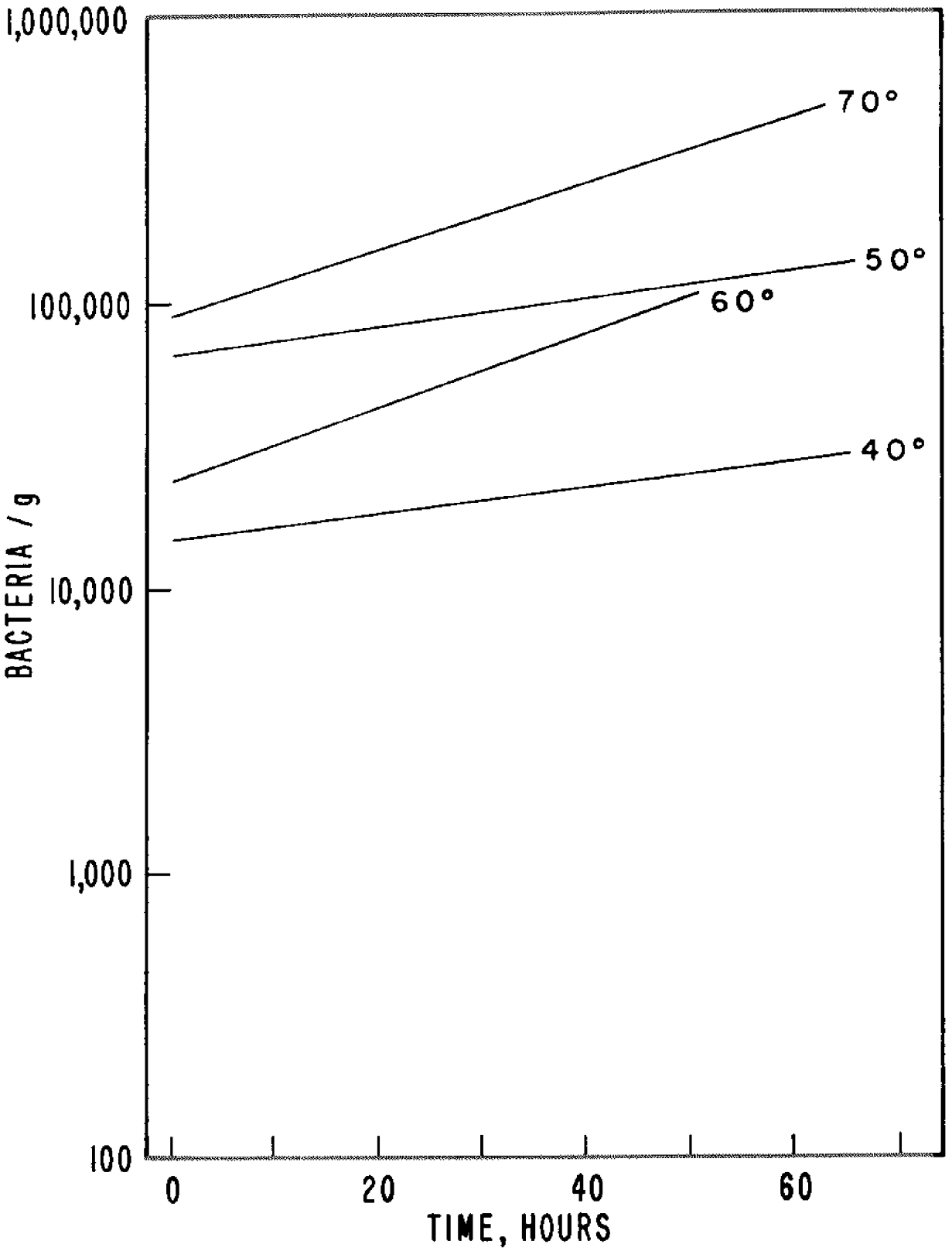
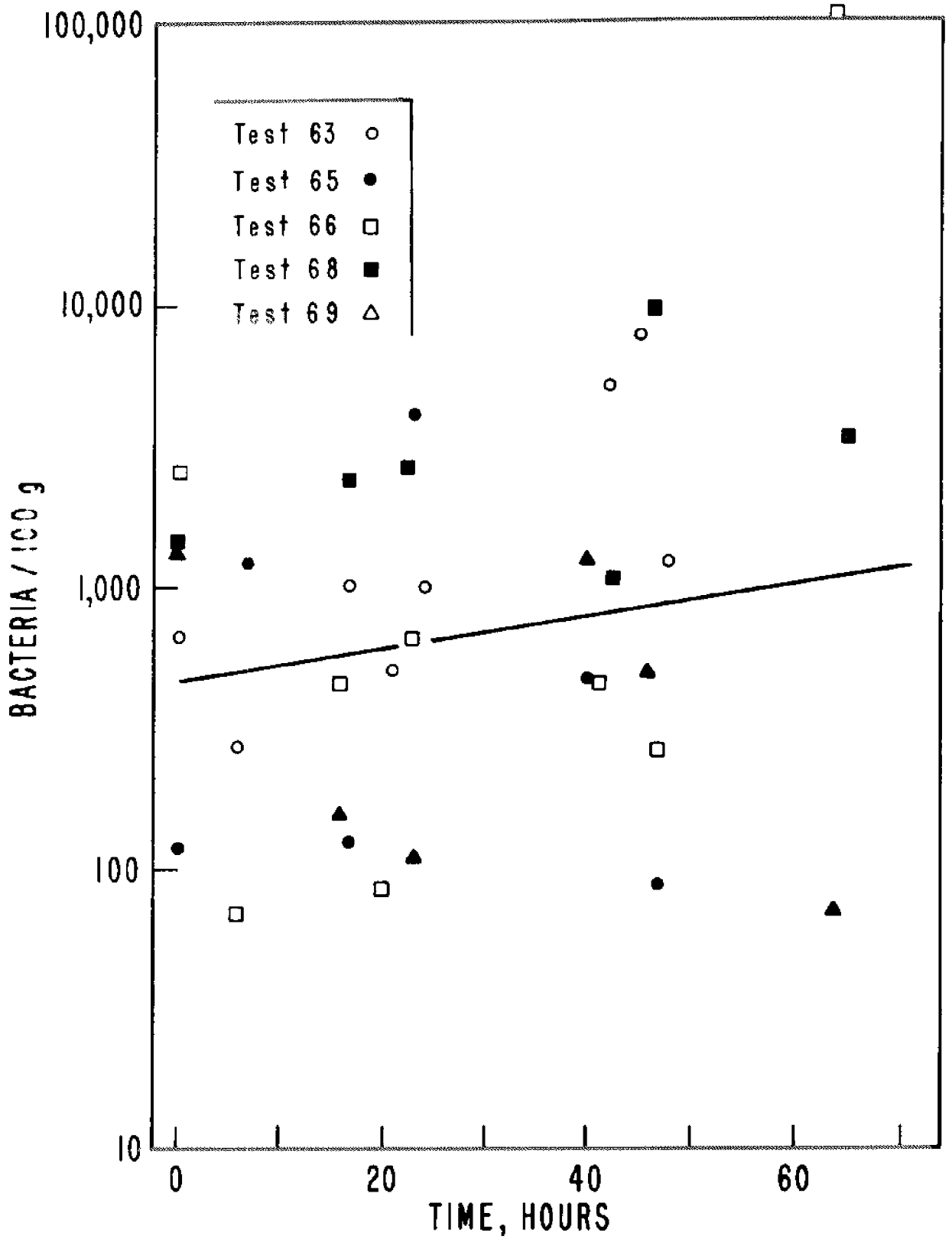


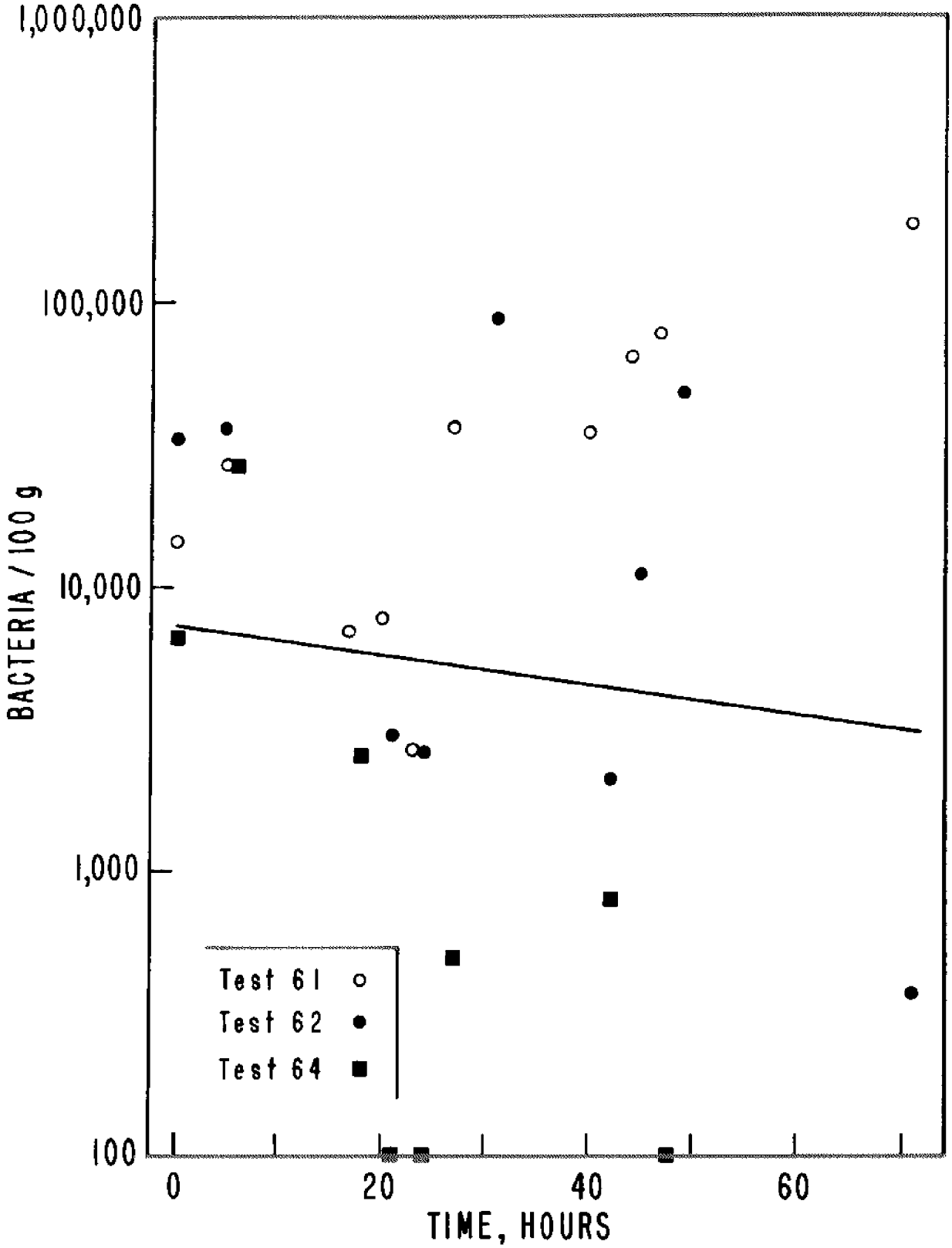
Plate count as a function of time for clams harvested during Summer 1974 and held at a constant temperature of 70°F.



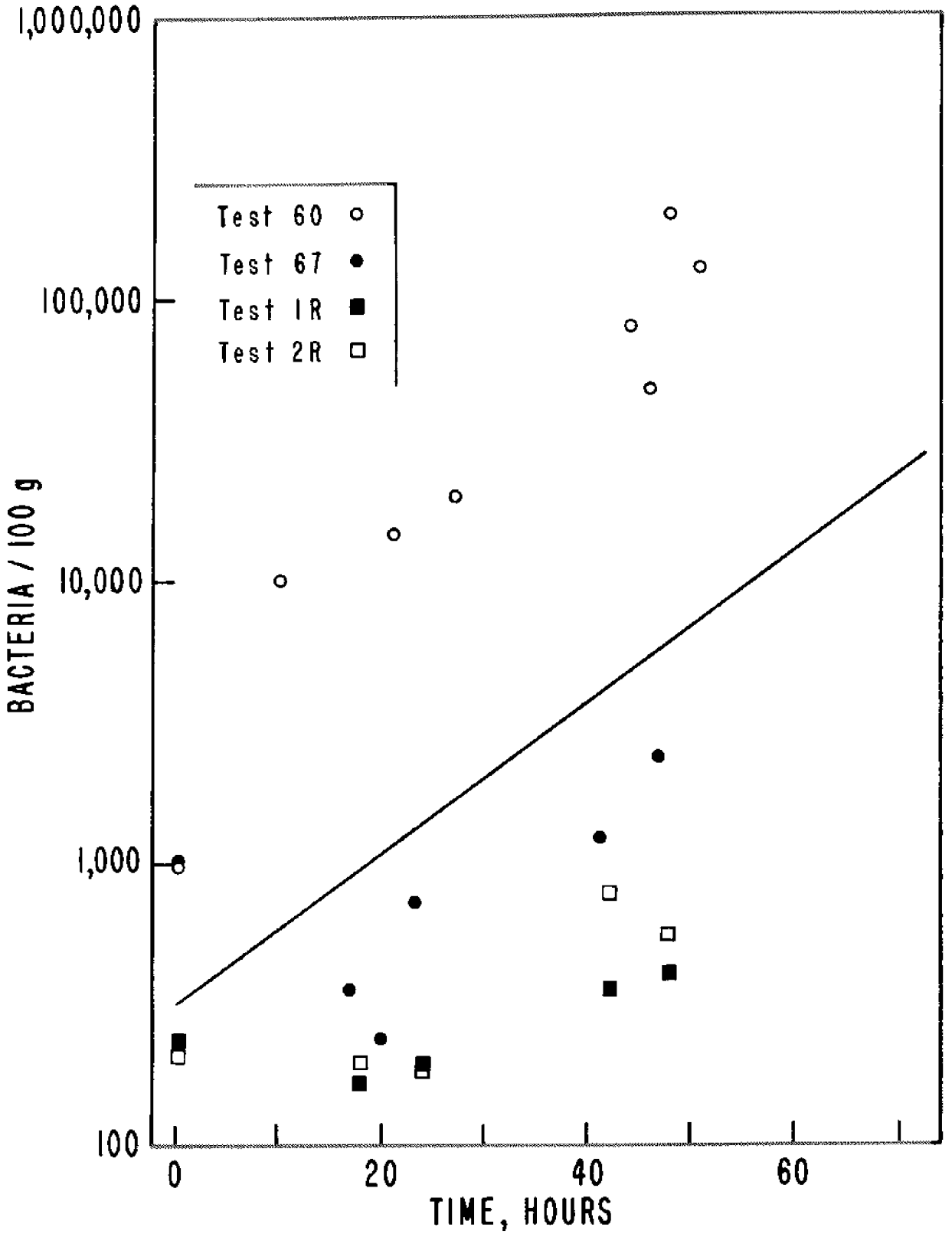
Summary of plate counts as a function of time for clams harvested during Summer 1974 and held at the indicated temperatures.



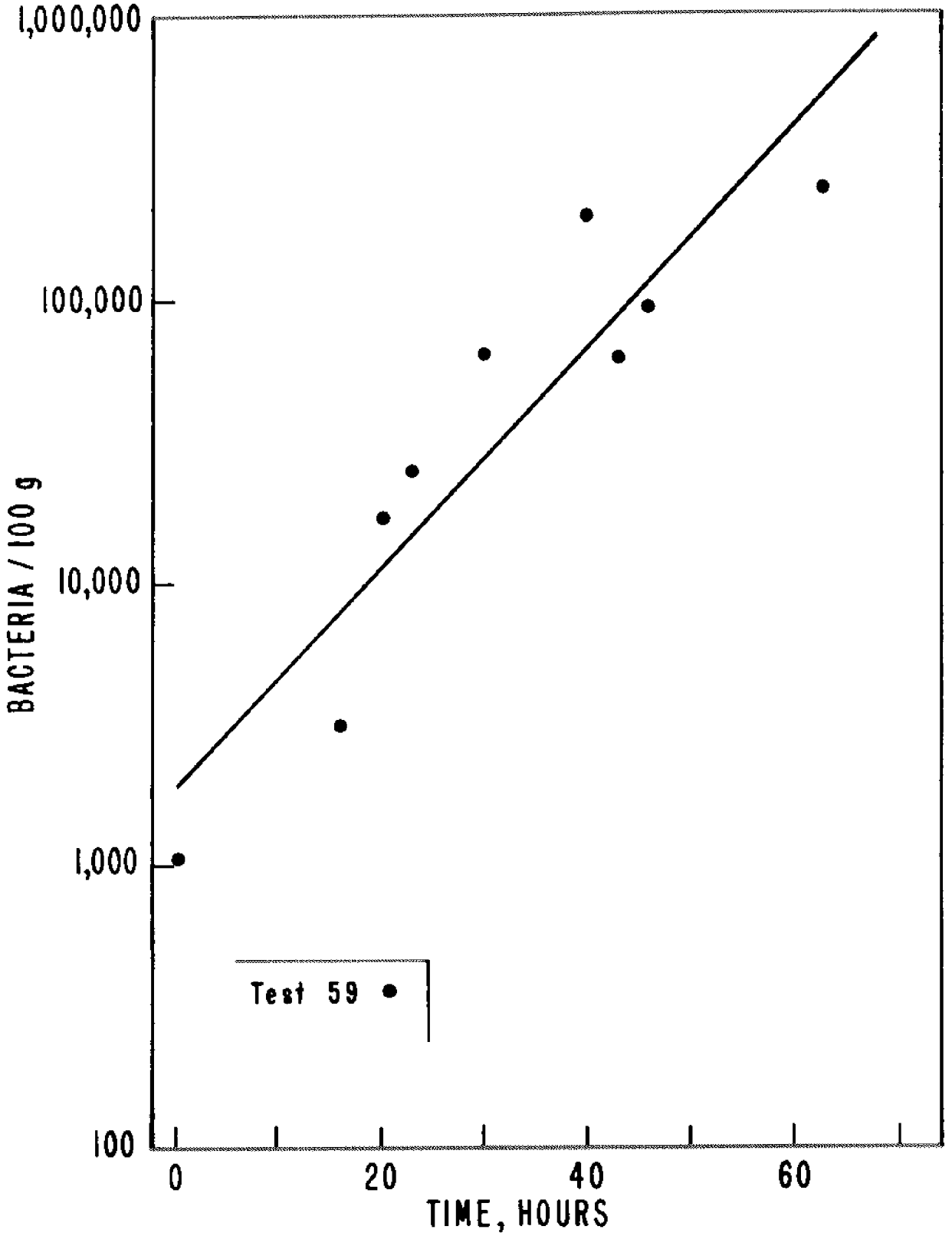
Total coliform count as a function of time for clams harvested during Summer 1974 and held at a constant temperature of 40°F.



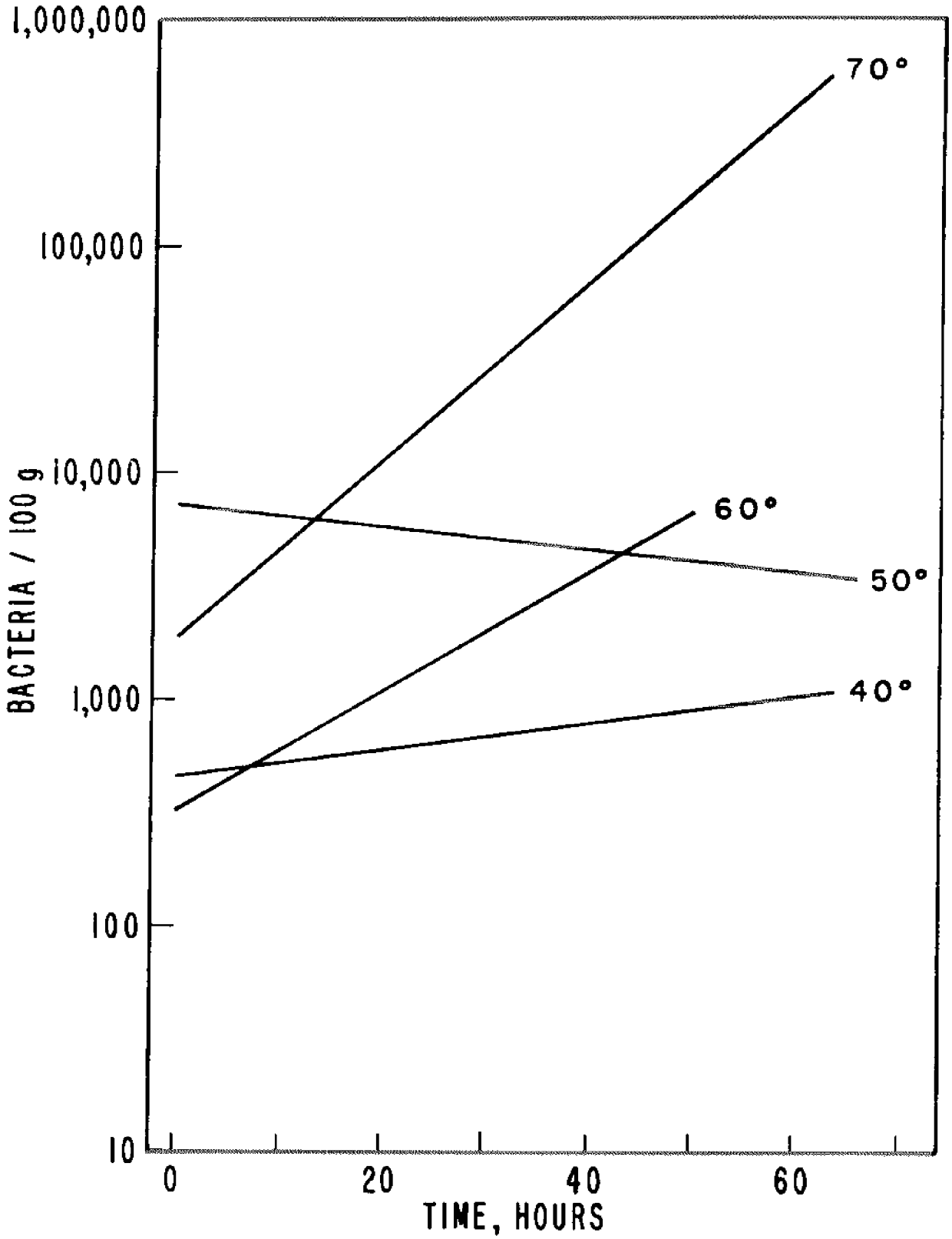
Total coliform count as a function of time for clams harvested during Summer 1974 and held at a constant temperature of 50°F.



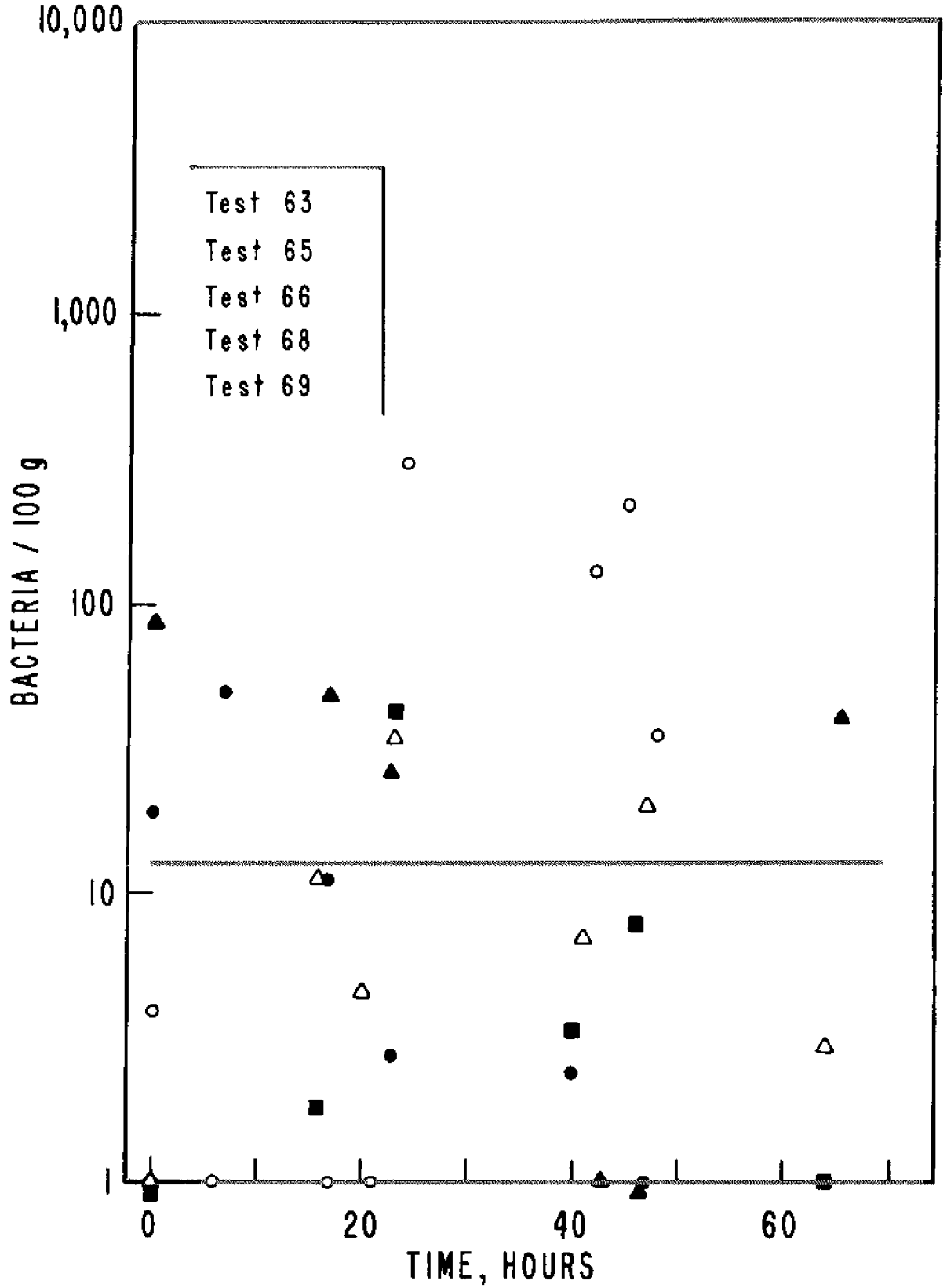
Total coliform count as a function of time for clams harvested during Summer 1974 and held at a constant temperature of 60°F.



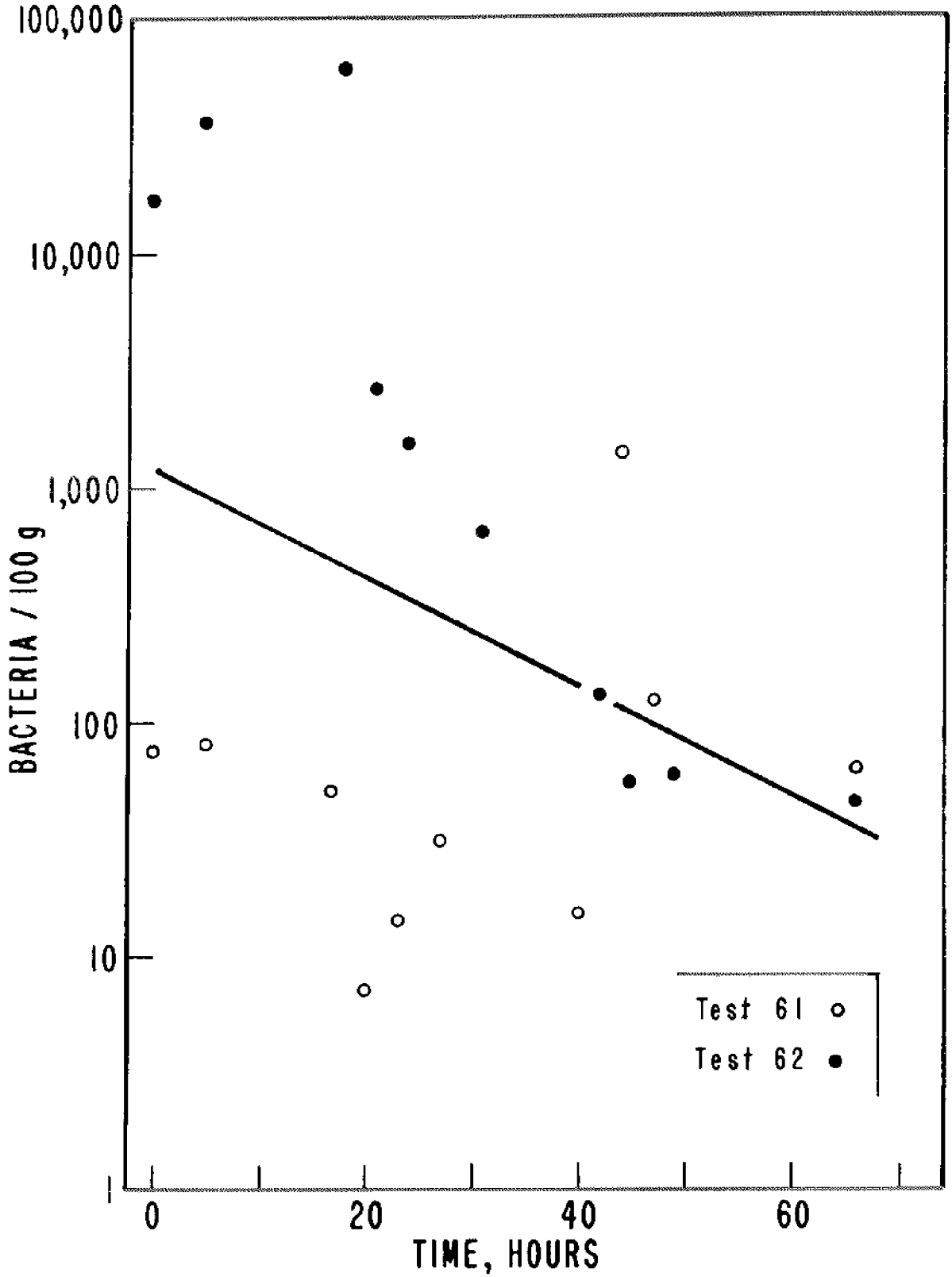
Total coliform count as a function of time for clams harvested during Summer 1974 and held at a constant temperature of 70°F.



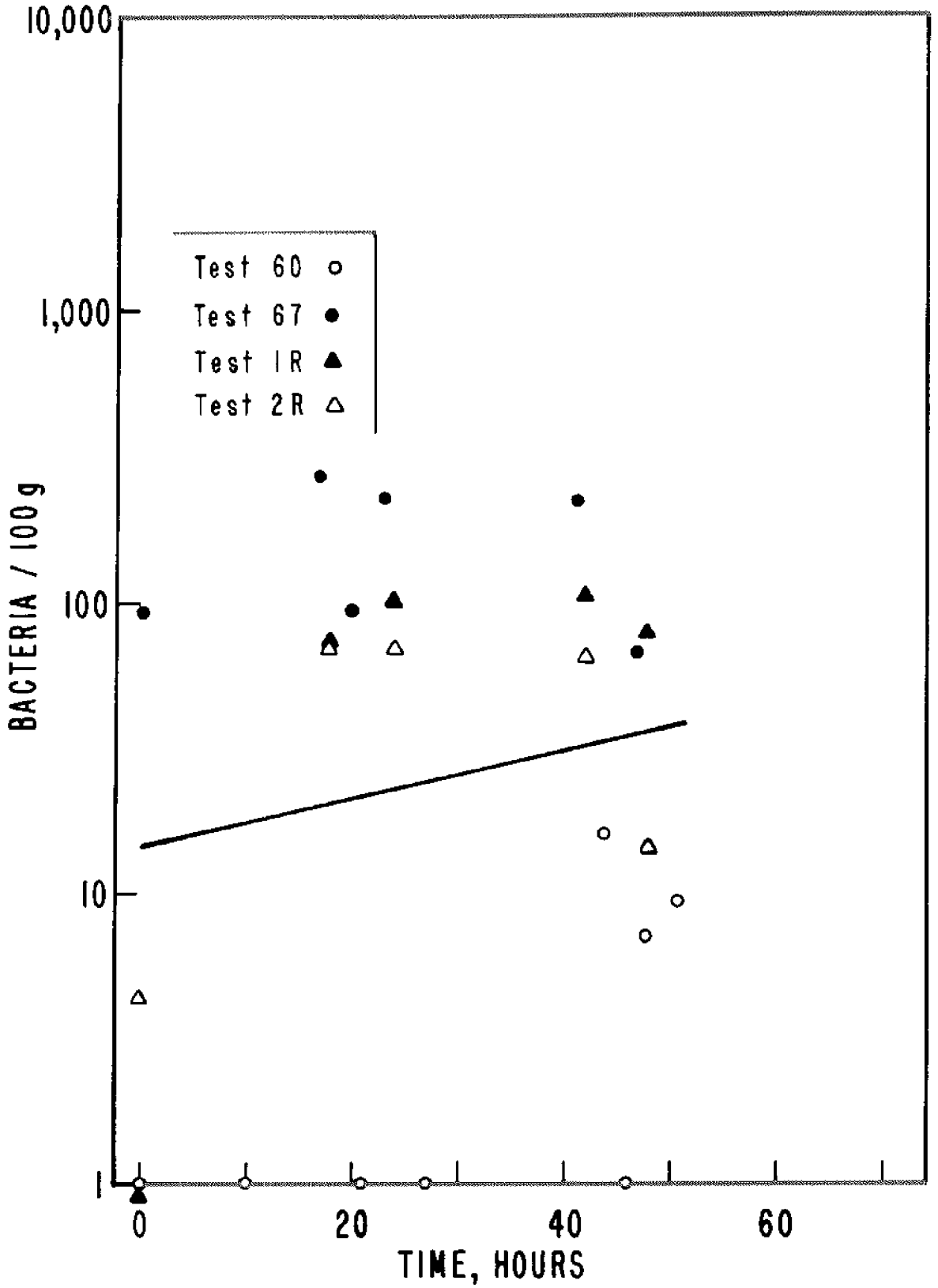
Summary of total coliform counts as a function of time for clams harvested during Summer 1974 and held at the indicated temperatures.



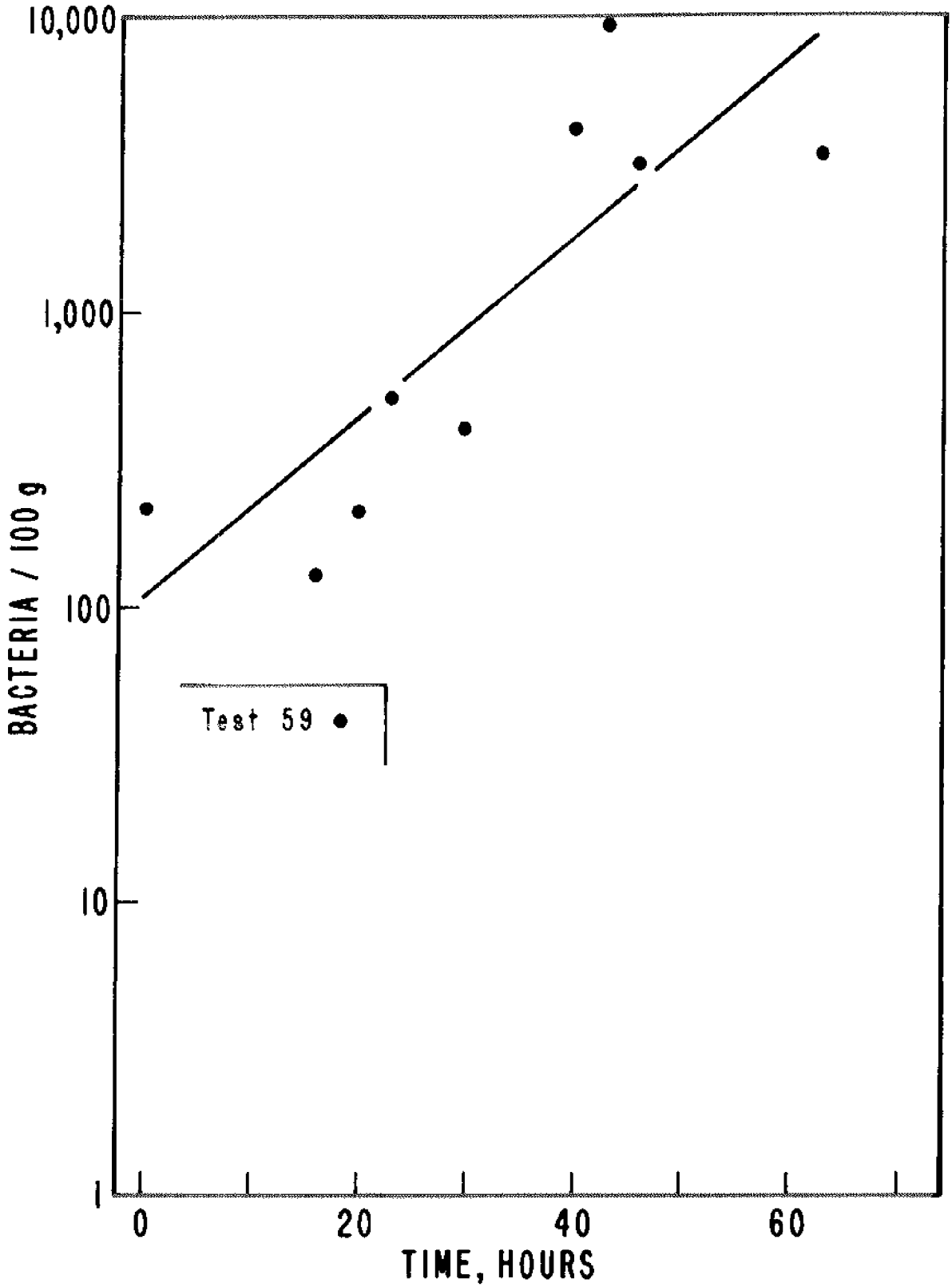
Fecal coliform count as a function of time for clams harvested during Summer 1974 and held at a constant temperature of 40°F.



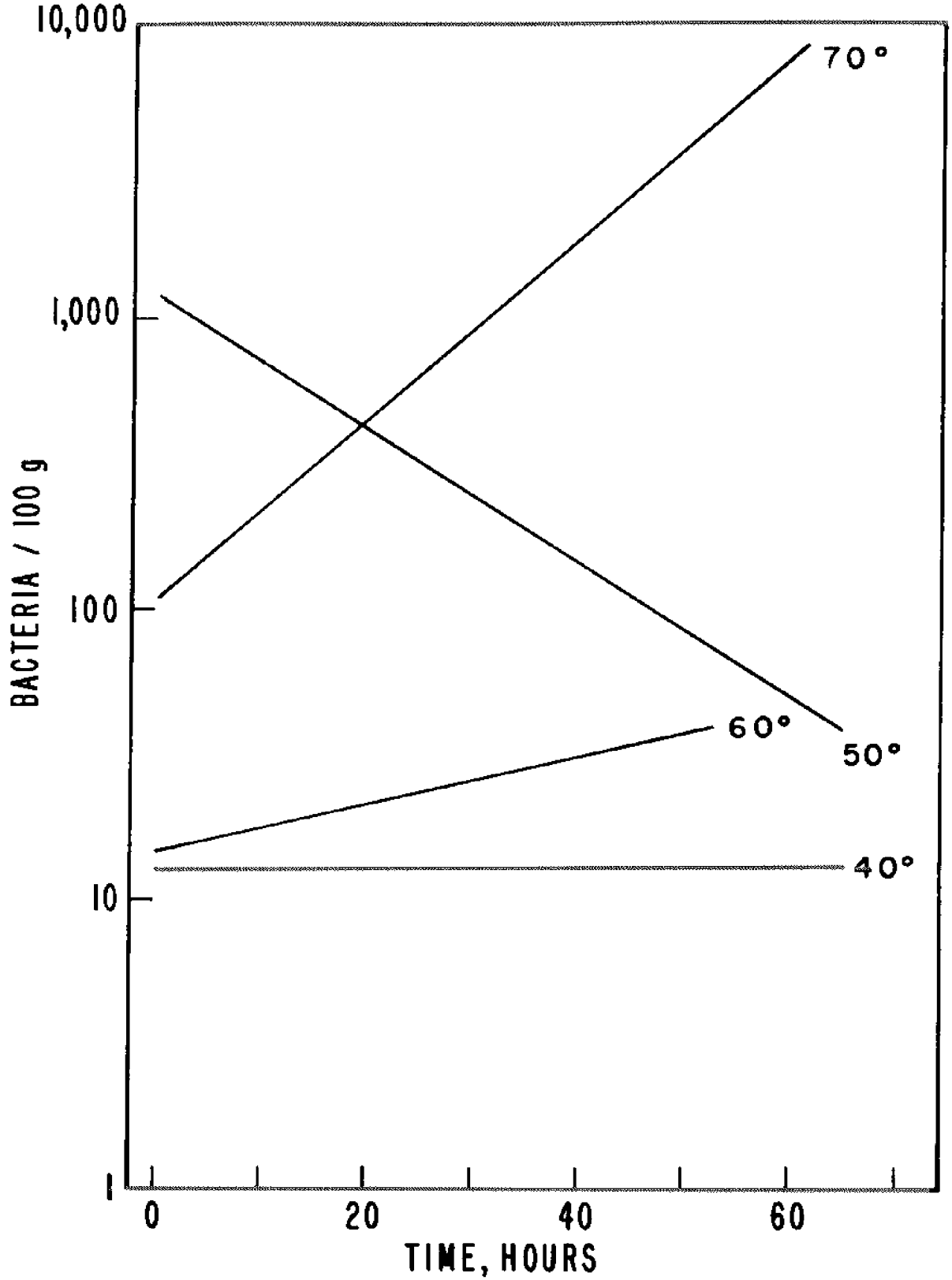
Fecal coliform count as a function of time for clams harvested during Summer 1974 and held at a constant temperature of 50°F.



Fecal coliform count as a function of time for clams harvested during Summer 1974 and held at a constant temperature of 60°F.



Fecal coliform count as a function of time for clams harvested during Summer 1974 and held at a constant temperature of 70°F.



Summary of fecal coliform counts as a function of time for clams harvested during Summer 1974 and held at the indicated temperatures.

Appendix A-4

Winter 1974-75

Plate Counts at
40, 50, 60, 70°F

Total Coliform Counts at
40, 50, 60, 70°F

Fecal Coliform Counts at
40, 50, 60, 70°F

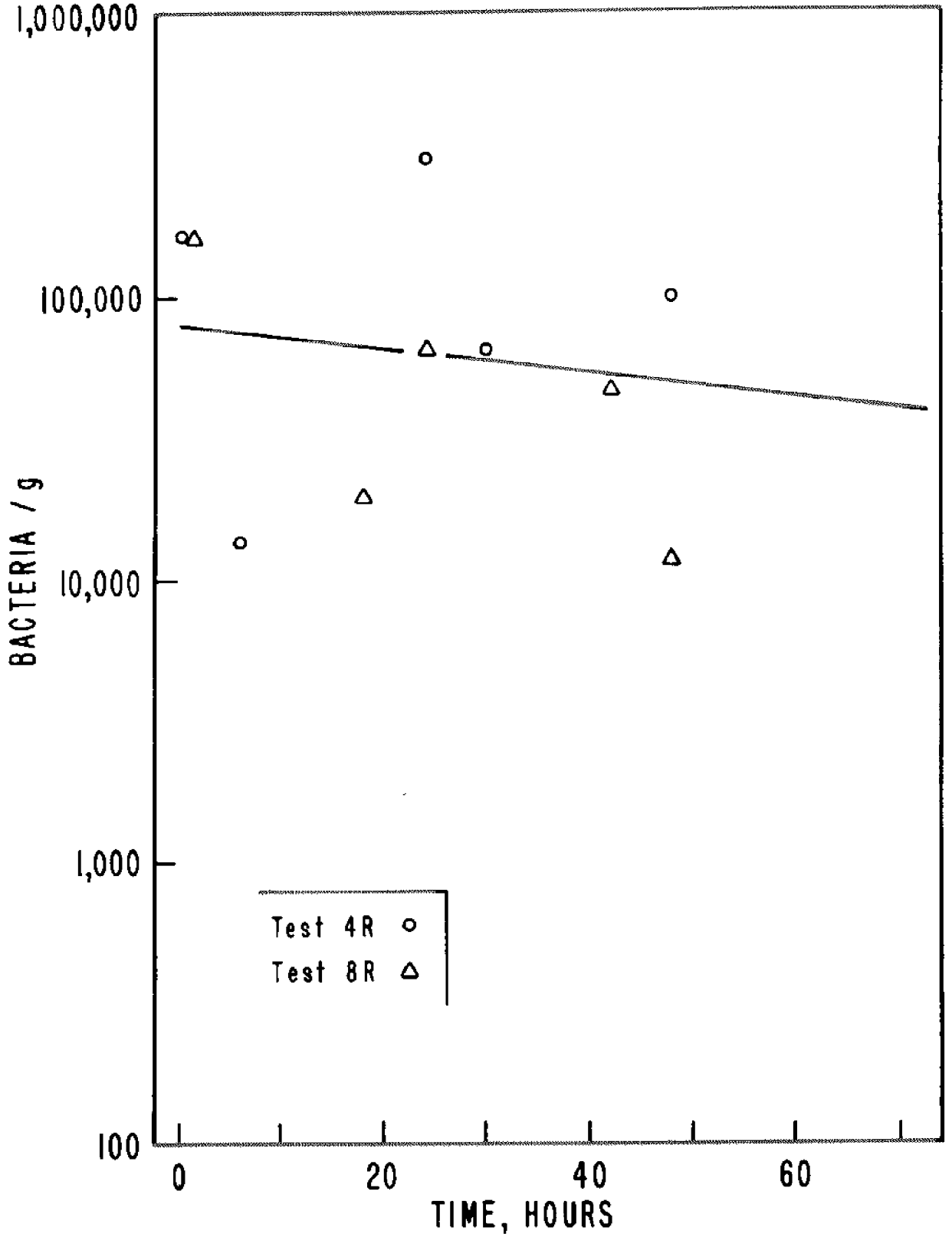


Plate count as a function of time for clams harvested during Winter 1974-75 and held at a constant temperature of 40°F.

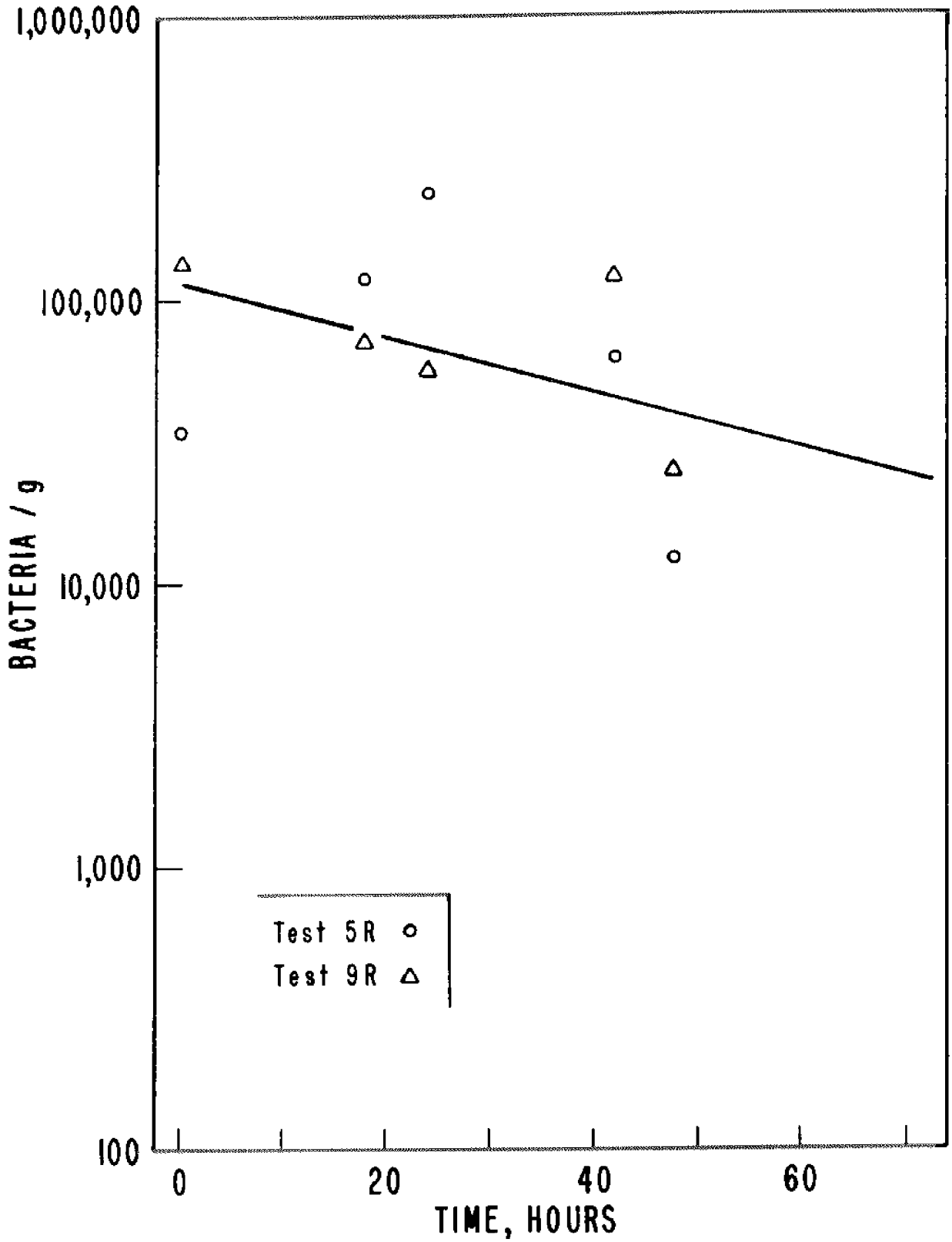


Plate count as a function of time for clams harvested during Winter 1974-75 and held at a constant temperature of 50°F.

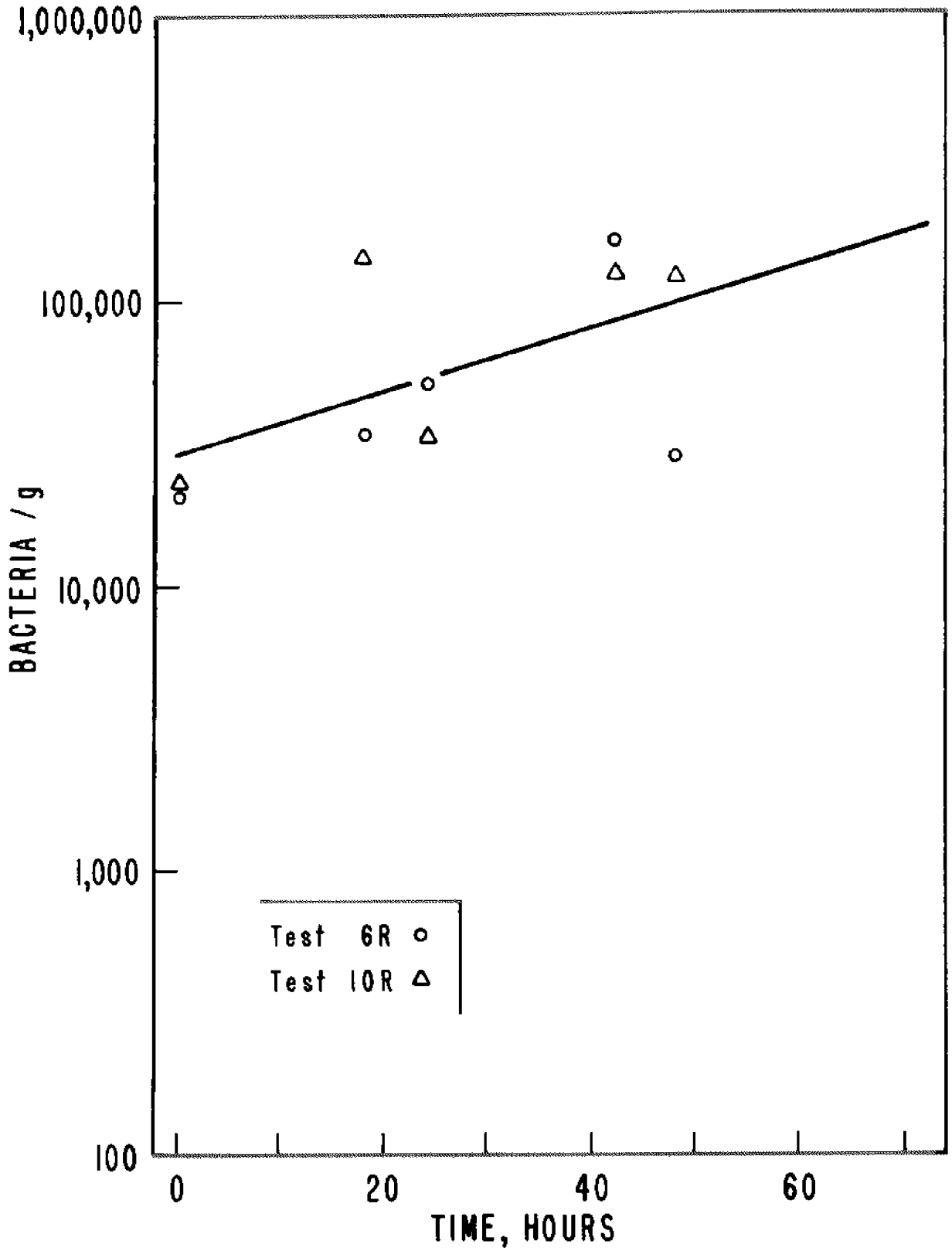


Plate count as a function of time for clams harvested during Winter 1974-75 and held at a constant temperature of 60°F.

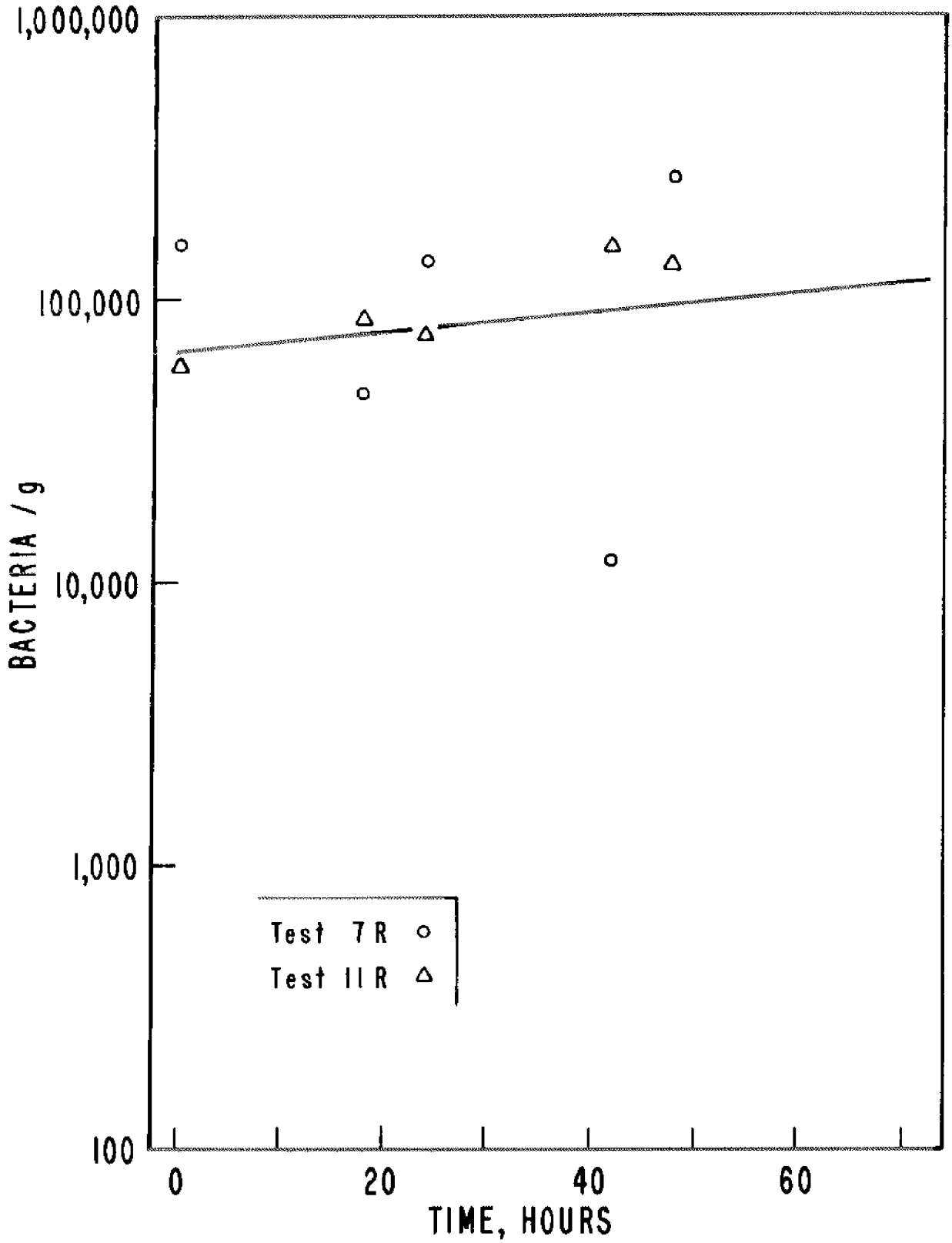
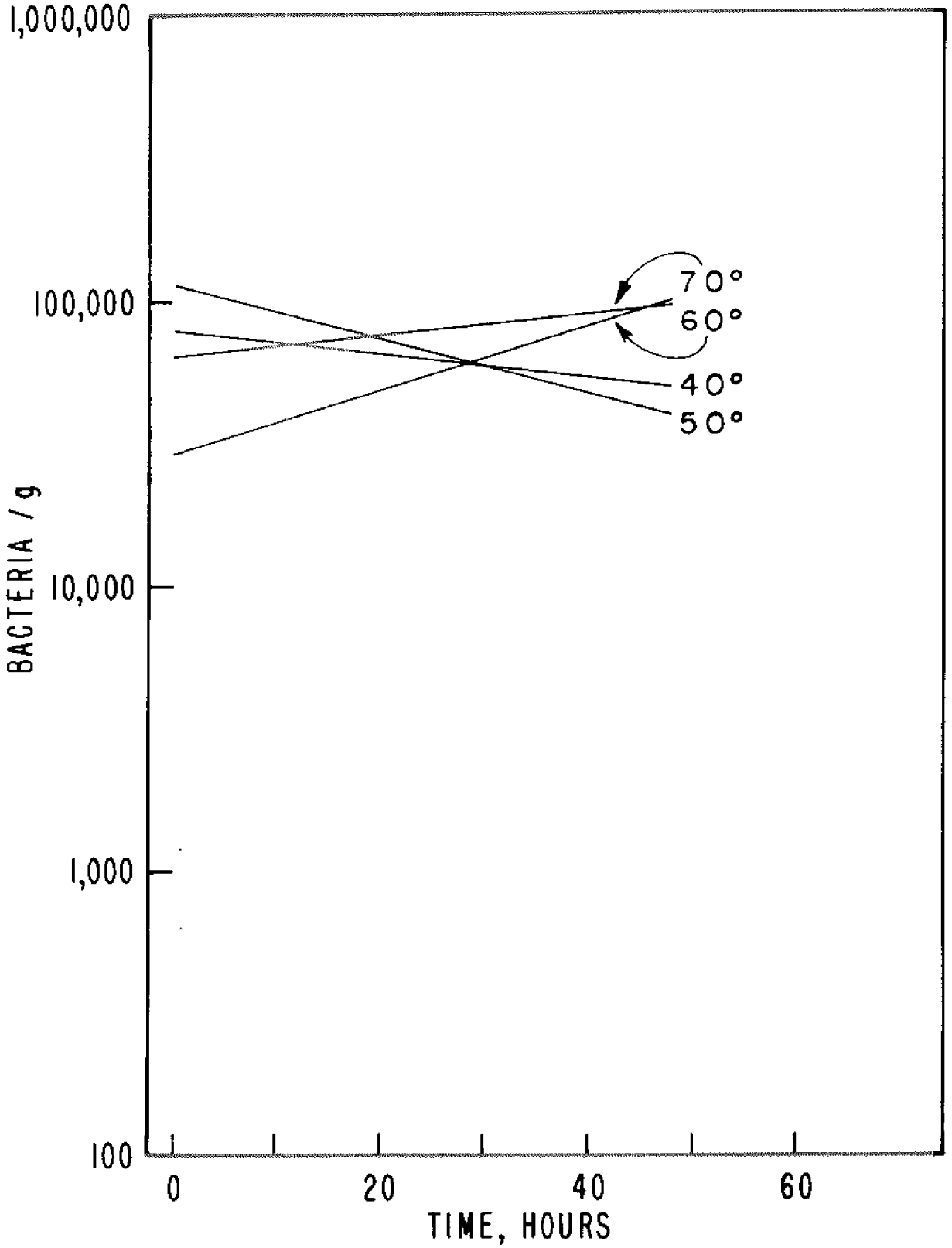
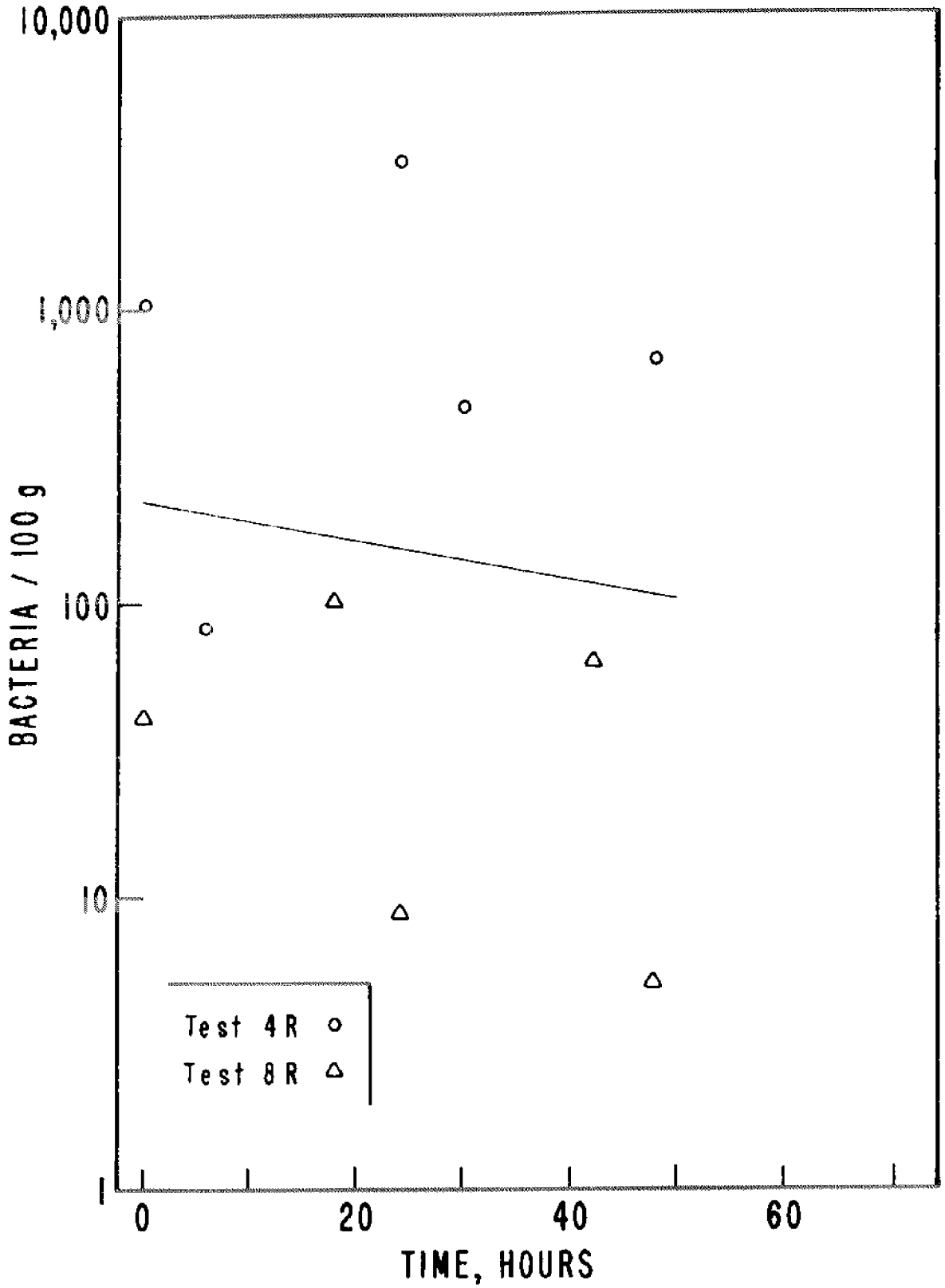


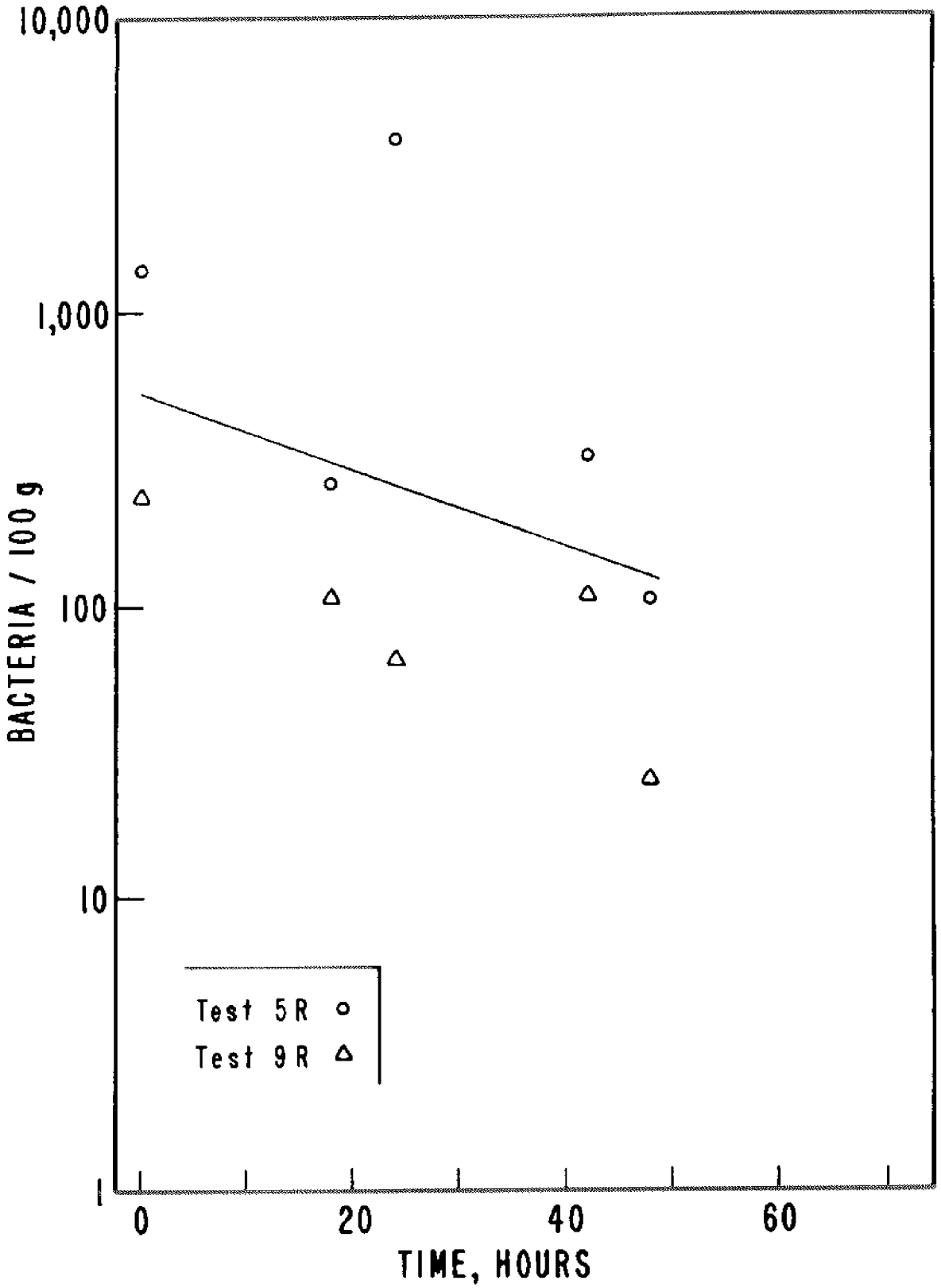
Plate count as a function of time for clams harvested during Winter 1974-75 and held at a constant temperature of 70°F.



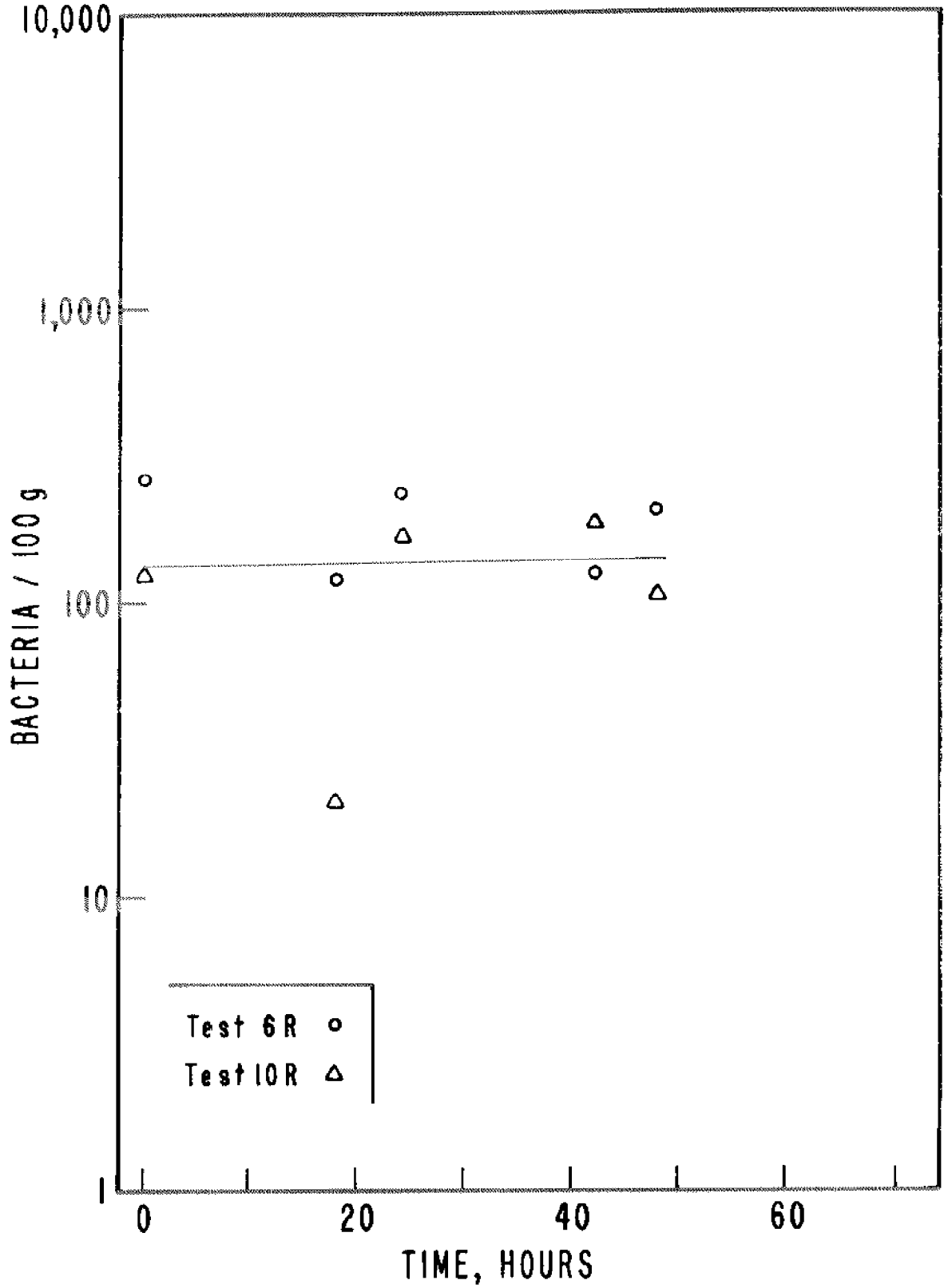
Summary of plate counts as a function of time for clams harvested during Winter 1974-75 and held at the indicated temperatures.



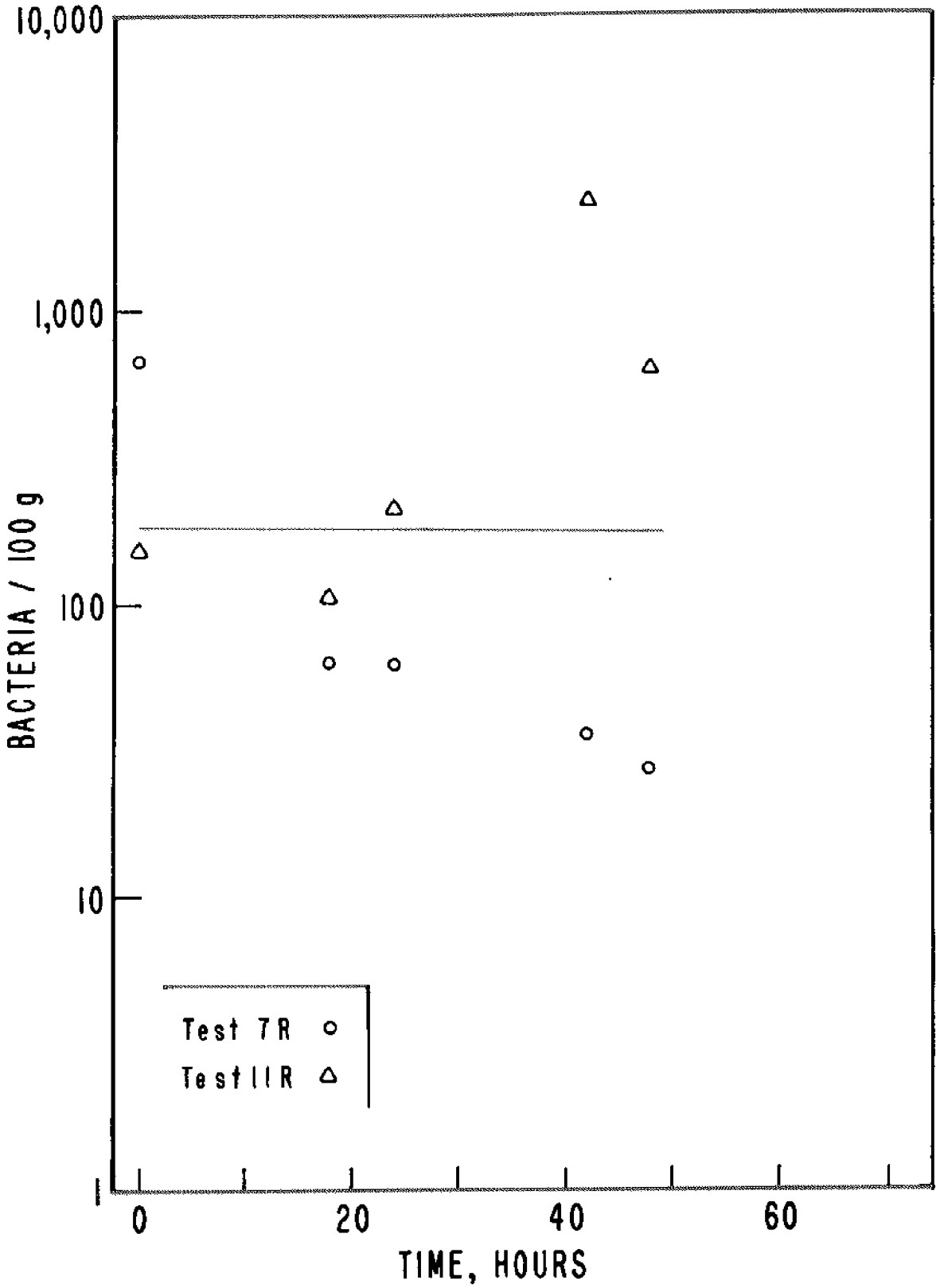
Total coliform count as a function of time for clams harvested during Winter 1974-75 and held at a constant temperature of 40°F.



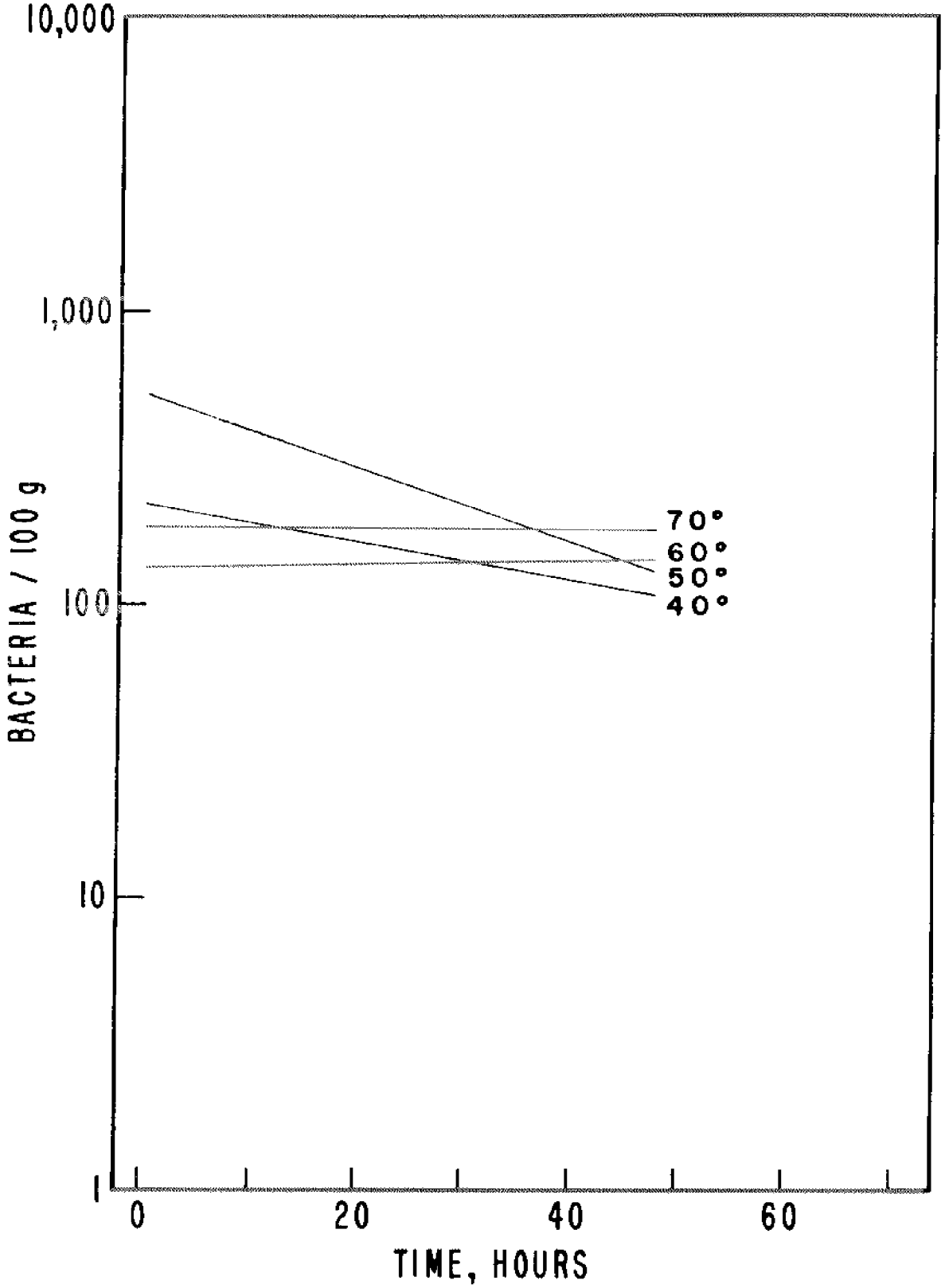
Total coliform count as a function of time for clams harvested during Winter 1974-75 and held at a constant temperature of 50°F.



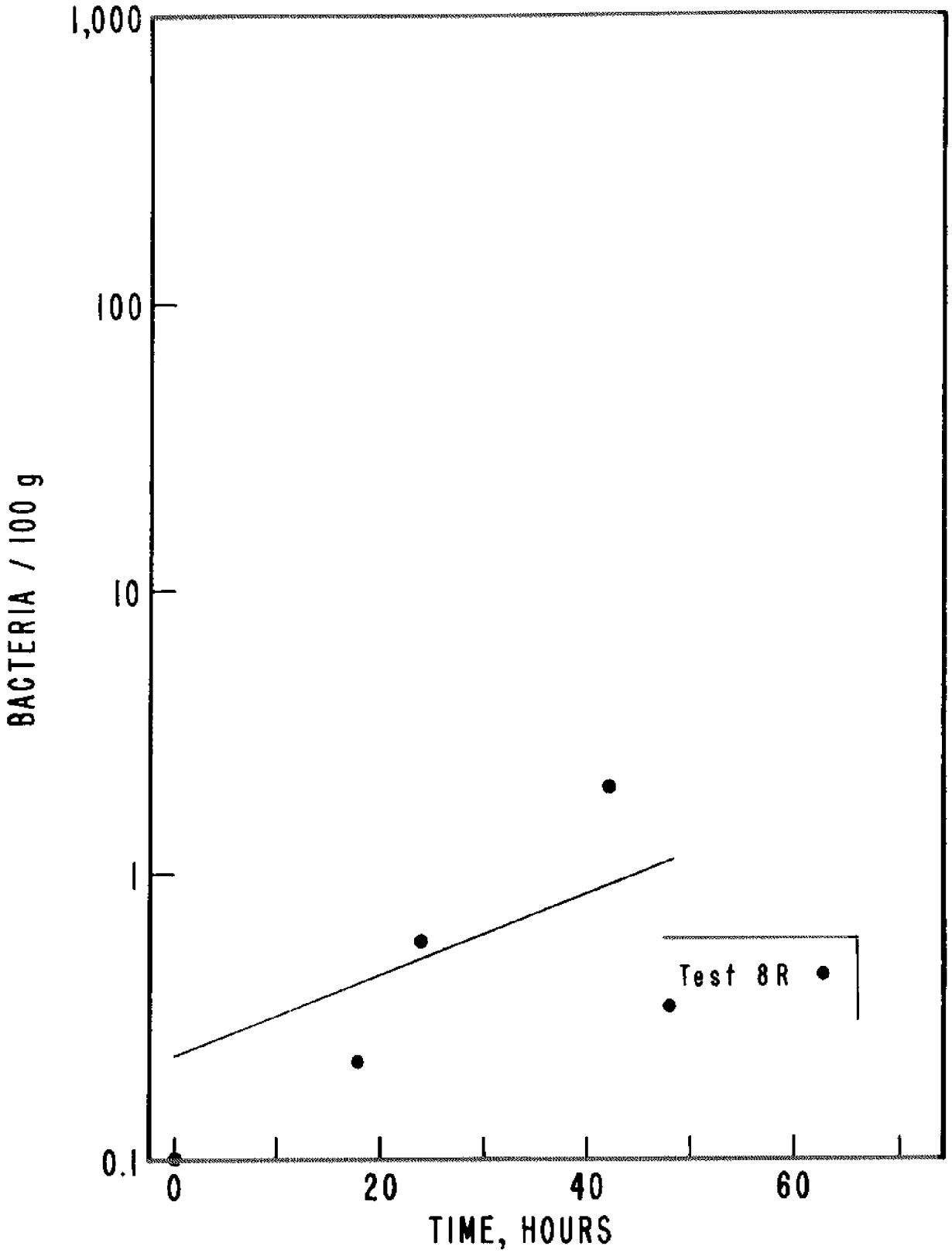
Total coliform count as a function of time for clams harvested during Winter 1974-75 and held at a constant temperature of 60°F.



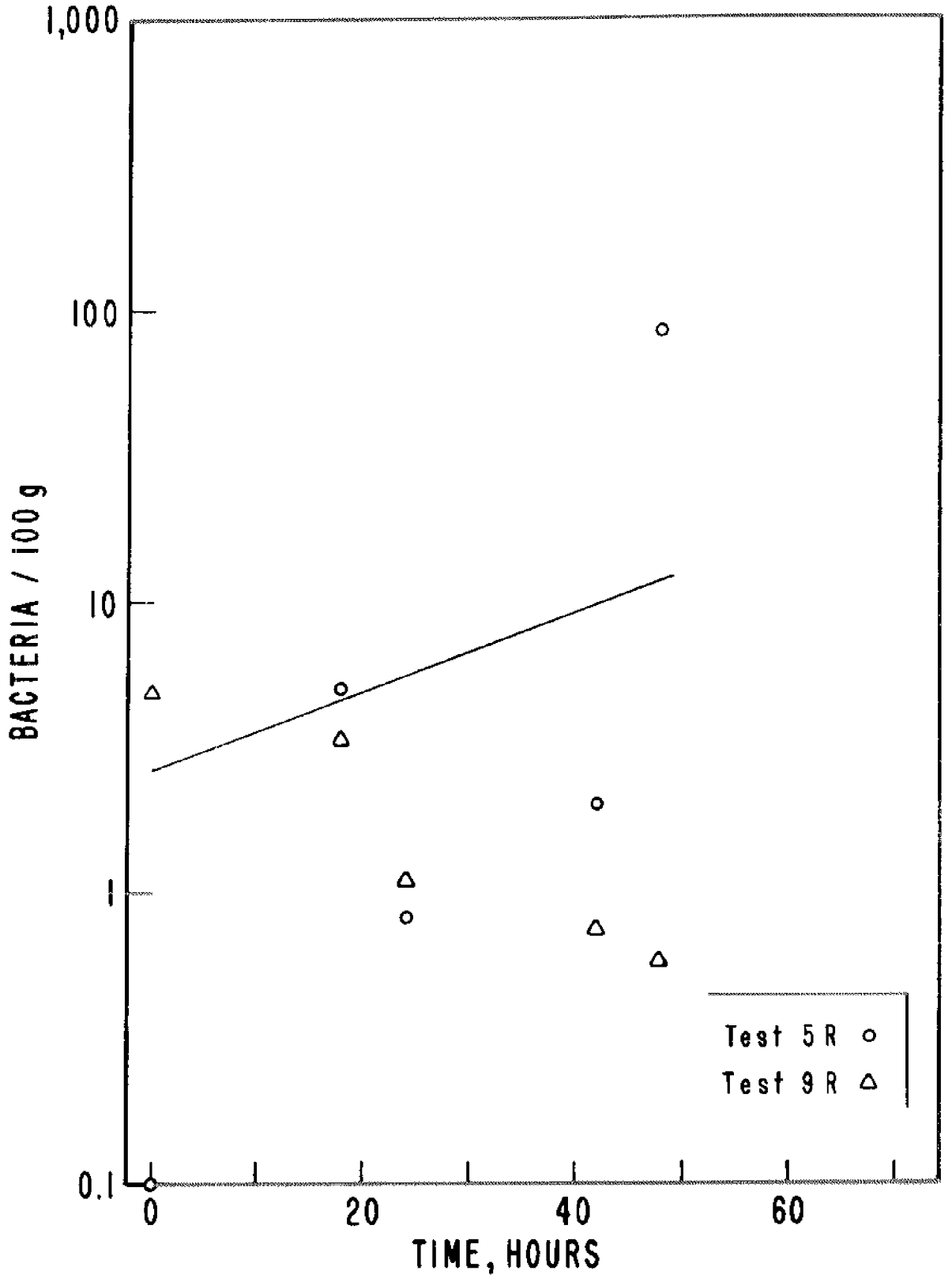
Total coliform count as a function of time for clams harvested during Winter 1974-75 and held at a constant temperature of 70°F.



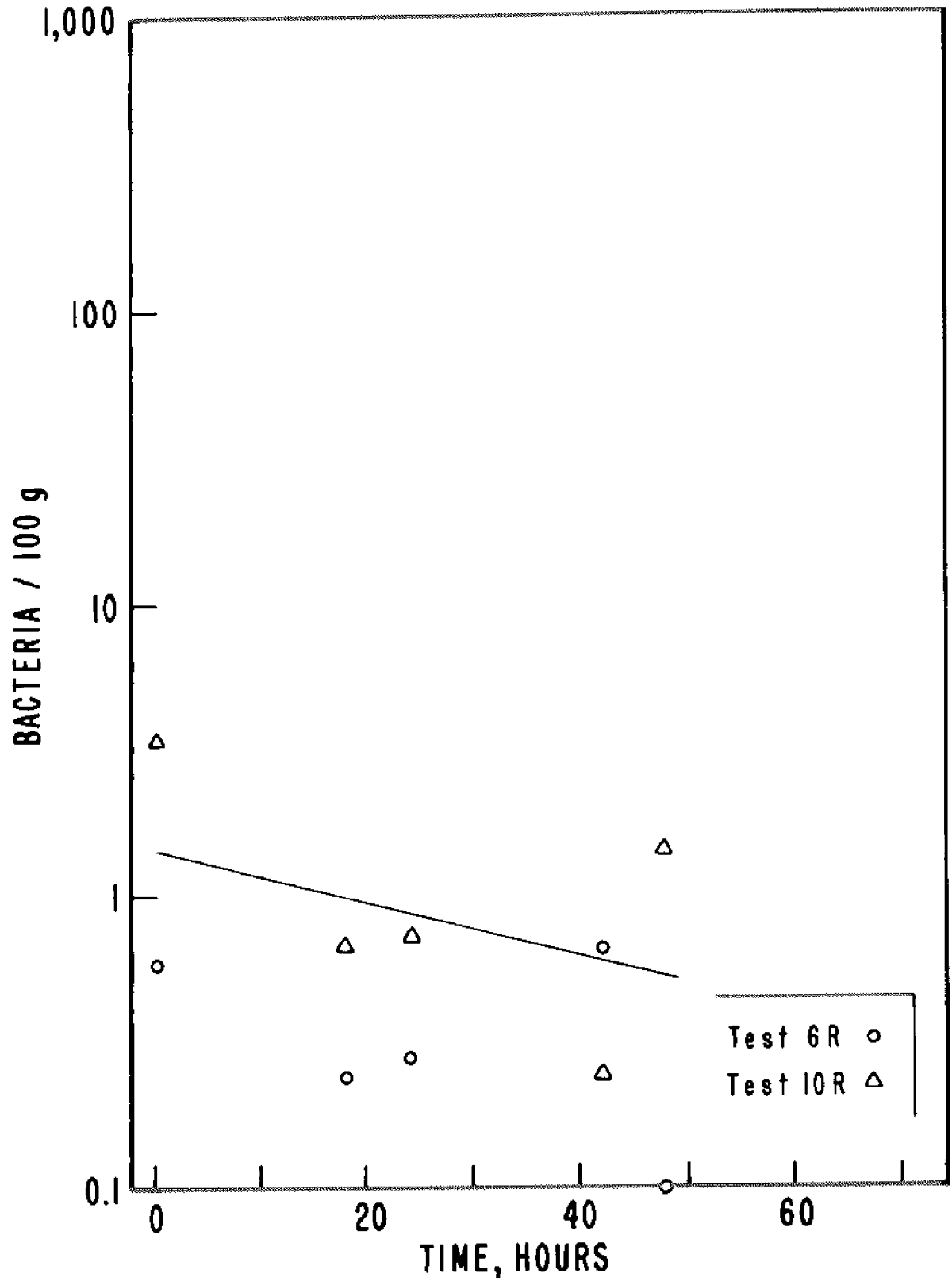
Summary of total coliform counts as a function of time for clams harvested during Winter 1974-75 and held at the indicated temperatures.



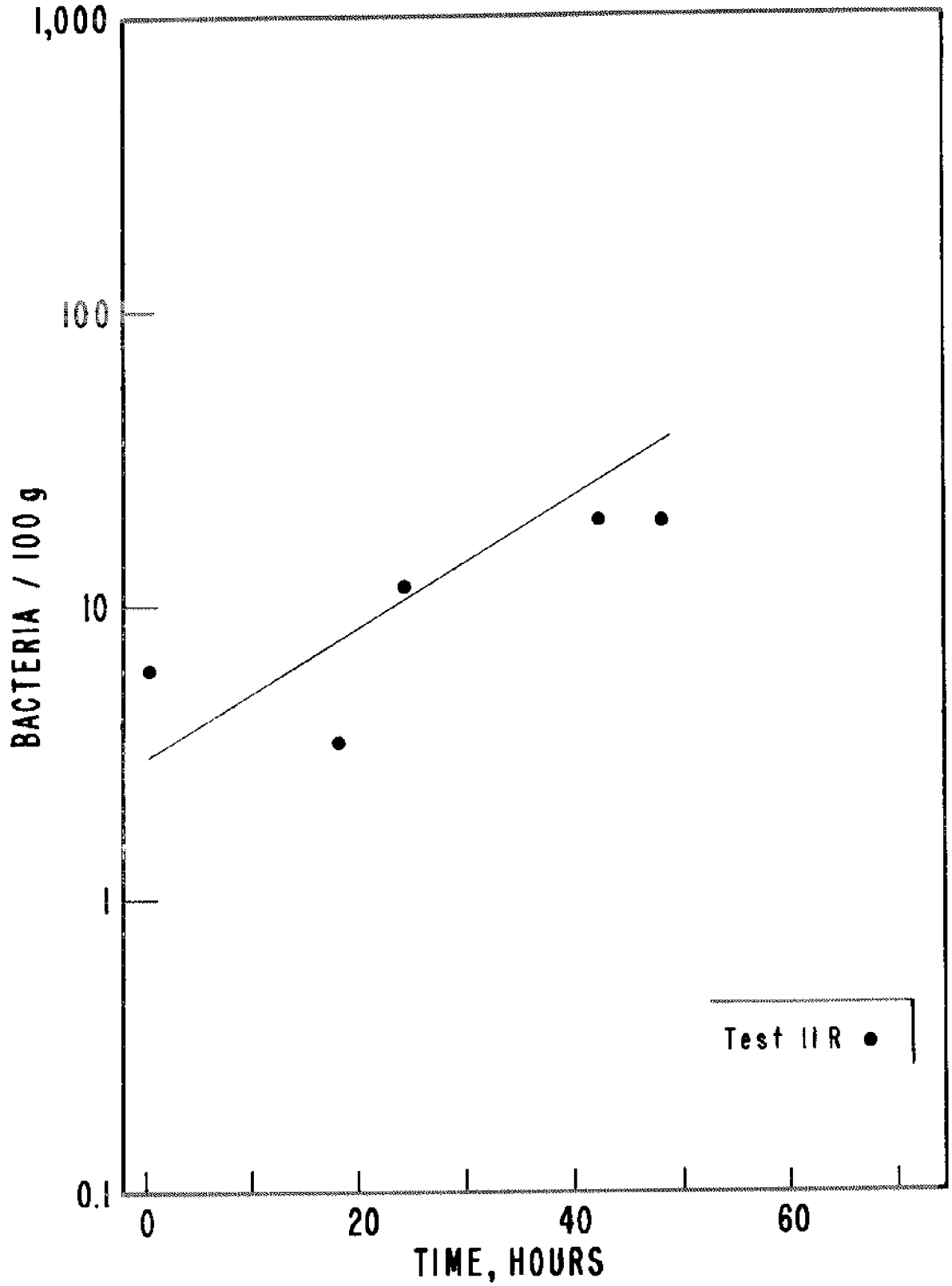
Fecal coliform count as a function of time for clams harvested during Winter 1974-75 and held at a constant temperature of 40°F.



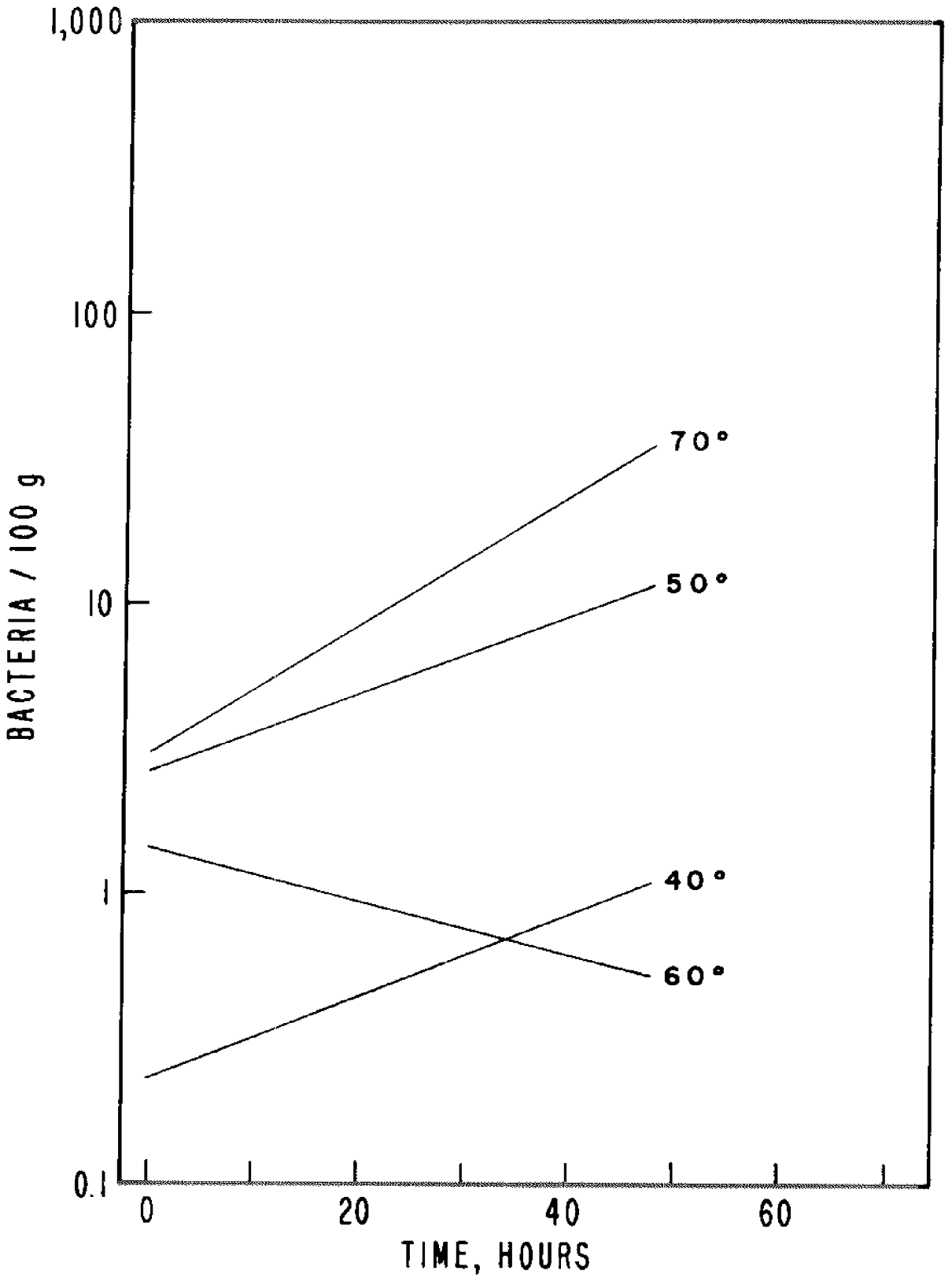
Fecal coliform count as a function of time for clams harvested during Winter 1974-75 and held at a constant temperature of 50°F.



Fecal coliform count as a function of time for clams harvested during Winter 1974-75 and held at a constant temperature of 60°F.



Fecal coliform count as a function of time for clams harvested during Winter 1974-75 and held at a constant temperature of 70°F.



Summary of fecal coliform counts as a function of time for clams harvested during Winter 1974-75 and held at the indicated temperatures.

APPENDIX 5

Bacterial Data from the 1975 On-board (i.e. harvesting boat) Cooling Studies

DATA - 1975 ON-BOARD COOLING STUDIES - PLATE COUNT (X 1000), BACTERIA/gram

HOUR	BSKT NO.	TEST NUMBER 1	2	3*	4	5	6	7**	8**	9
	1	298.0	520.0	X	468.0	140.0	2320.0	132.0	X	1065.0
		420.0	61.0	21200.	273.0	78.0	1910.0	95.0	935.0	411.0
	3	278.0	850.0	X	4480.0	34.0	1170.0	112.0	X	531.0
		1290.0	242.5	1268.0	2780.0	44.5	1160.0	100.5	X	2132.0
0										
	2	249.5	430.0	20120.	302.0	122.5	1630.0	104.5	X	379.0
		790.0	307.0	11040.	277.0	101.0	2400.0	268.0	X	304.0
	4	349.0	284.0	X	417.0	156.0	1260.0	257.0	X	412.0
		420.0	322.0	6160.0	281.0	47.0	1580.0	122.0	X	57.0
	1	81.0	790.0	X	323.5	347.5	1530.0	X	1190.0	149.0
		306.5	86.5	X	231.5	124.0	1490.0	X	1037.0	289.5
	3	227.5	610.0	1132.0	374.0	315.0	630.0	1044.0	2800.0	465.0
		594.0	432.5	828.0	539.0	40.0	230.0	96.5	2400.0	217.0
6										
	2	200.0	630.0	776.0	104.5	260.0	1320.0	X	1490.0	160.0
		143.0	550.0	X	81.0	57.0	1640.0	251.0	519.0	128.5
	4	890.0	X	176.0	229.0	108.0	226.0	70.0	7320.0	281.0
		570.0	140.0	X	154.0	169.0	297.0	82.5	685.0	480.0
	1	2770.0	600.0	10.0	220.0	291.5	226.0	X	3600.0	549.0
		1760.0	104.0	389.5	453.0	106.0	168.0	X	1620.0	255.0
	3	143.0	910.0	326.0	552.0	211.0	251.5	X	2880.0	X
		2340.0	680.0	190.0	932.0	227.5	980.0	X	X	X
25										
	2	225.0	252.0	504.0	322.5	413.0	308.0	X	1610.0	131.5
		X	2220.0	261.0	192.0	276.0	181.0	X	1500.0	550.0
	4	2520.0	287.0	308.0	111.0	605.5	580.0	X	2520.0	X
		990.0	X	X	146.0	266.5	X	X	1890.0	200.0
	1	1440.0	640.0	378.0	722.0	238.0	2470.0	X	234.0	450.0
		309.0	X	X	212.0	90.0	1610.0	X	2450.0	487.0
	3	284.0	358.0	492.0	168.0	2470.0	1540.0	332.5	1540.0	435.0
		274.0	114.0	585.5	257.0	1610.0	1950.0	288.0	2780.0	263.0
49										
	2	810.0	331.5	29.0	622.0	1540.0	3280.0	X	1800.0	205.0
		238.5	280.0	108.0	1800.0	1950.0	1922.0	3430.0	2470.0	123.5
	4	57.0	253.5	58.0	204.5	3280.0	269.0	397.5	1700.0	454.0
		2670.0	420.0	244.5	206.5	1922.0	310.0	253.5	1340.0	275.0

DATA - 1975 ON-BOARD COOLING STUDIES - PLATE COUNT (X 1000),BACTERIA/gram (continued)

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* Plate count test number 3 not used due to lab analysis difficulties.

X No results due to lab error or TNTC (too numerous to count).

** Tests 7 and 8 for plate count not used.
A Fecal Coliform count of 1300 not included (Test 8, basket 4, 6-1/2 hrs.)

DATA - 1975 ON-BOARD COOLING STUDIES - PLATE COUNT (X 1000), BACTERIA/gram (continued)

HOUR	BSKT NO.	TEST NUMBER 10	11	12	13	14	15	16	17
	1	73.5	224.5	4.0	62.0	310.0	81.5	141.0	350.0
		191.0	84.0	22.0	151.0	147.0	85.0	22.5	133.0
	3	X	74.0	244.0	81.5	27.0	16.0	35.0	123.0
		X	75.0	34.0	144.0	X	198.0	48.0	235.0
0									
	2	75.5	99.5	19.0	30.0	85.0	73.0	158.0	172.5
		X	37.0	63.0	101.0	10.0	92.0	19.5	107.0
	4	38.0	57.0	37.5	159.0	24.0	66.5	560.5	421.0
		80.0	188.0	33.5	210.5	17.5	80.0	32.5	55.0
	1	972.5	110.0	33.0	296.0	190.0	160.0	92.5	185.5
		120.0	87.5	18.0	171.5	34.0	1980.0	91.5	156.0
	3	124.0	32.0	11.0	172.0	130.5	23.0	78.5	67.5
		371.5	52.5	24.0	168.0	72.0	155.0	79.0	112.0
6									
	2	26.0	122.5	26.5	185.0	480.0	72.0	66.5	152.0
		93.0	63.5	24.5	137.5	170.0	167.0	34.5	188.0
	4	1240.0	119.0	49.0	41.5	26.0	17.5	13.0	58.5
		X	80.5	54.0	52.0	97.5	42.5	30.0	67.5
	1	98.5	64.5	33.0	70.5	95.0	81.0	295.0	85.0
		472.0	201.0	139.0	159.0	181.0	122.0	373.0	218.5
	3	162.5	178.0	37.5	154.0	97.0	77.5	155.5	258.0
		218.0	189.0	310.5	348.0	124.0	90.0	1030.0	105.5
25									
	2	85.5	40.0	162.0	65.0	70.5	82.5	92.0	54.5
		84.5	52.0	219.0	1480.0	172.0	22.0	65.5	38.0
	4	94.0	162.0	42.0	288.5	170.0	210.0	130.5	127.5
		25.5	170.0	39.5	138.0	139.5	73.5	223.0	169.5
	1	323.0	62.5	58.5	92.0	121.5	325.5	220.0	400.0
		122.0	106.0	111.5	93.0	23.0	146.0	370.0	220.0
	3	1050.0	468.0	83.5	204.0	X	175.5	1000.0	112.0
		1060.0	940.0	132.0	188.5	X	X	154.5	154.0
49									
	2	2560.0	80.0	79.5	96.5	43.0	790.0	65.0	126.5
		397.5	90.0	90.0	215.0	680.0	X	64.5	170.5
	4	83.5	148.0	29.0	130.0	X	121.0	100.0	314.0
		61.0	72.0	43.0	159.5	X	193.0	340.0	104.5

DATA - 1975 ON-BOARD COOLING STUDIES - TOTAL COLIFORM, BACTERIA/100 grams

HOUR	BSKT NO.	TEST NUMBER 1	2	3	4	5	6	7	8	9
	1	18	170	340	410	330	2300	68	43000	200
		110	490	280	11000	270	35000	330	2300	17000
	3	20	1100	340	640	1100	490	490	3300	24000
		45	330	320	640	340	210	230	2300	240000
0										
	2	130	410	4900	7900	400	460	160000	7900	1400
		110	1300	330	720	1700	330	1300	1300	2800
	4	0	330	4900	450	700	170	2200	300	54000
		130	1800	450	2300	1300	460	230	8100	4900
	1	470	270	560	160000	1300	3100	220	4900	560
		640	330	3300	640	320	1700	210	560	24000
	3	560	340	810	560	480	4600	480	11000	810
		1400	3300	2800	270	490	640	4900	3300	4300
6										
	2	330	100	2200	2300	450	260	200	4900	270
		490	270	400	2300	270	3300	790	240	4600
	4	170	170	54000	4900	790	410	270	250	410
		330	1300	3300	170	1100	7900	1700	24000	2200
	1	82	2300	320	540	1300	54000	490	320	810
		220	1700	4900	7000	2200	2300	330	4900	160000
	3	810	480	2800	35000	340	320	7900	280	35000
		340	4900	7900	24000	340	43000	1700	24000	24000
25										
	2	720	1700	540	4900	290	330	340	1100	720
		240000	490	470	520	1700	790	460	11000	4900
	4	93	340	24000	640	2300	340	93	1700	2200
		220	270	340	7000	17000	290	260	290	4900
	1	45	170	410	24000	340	7900	340	1300	2800
		20	400	370	13000	240000	7900	2300	4600	400
	3	170	4900	13000	24000	620	240000	560	24000	430
		210	13000	810	13000	2200	160000	240	4900	470
49										
	2	110	1700	480	3300	480	400	220	240000	1100
		220	480	290	290	3300	3300	210	1700	1100
	4	130	110	1700	17000	470	7900	120	410	240
		110	40	210	3300	2800	720	230	1700	240

DATA - 1975 ON-BOARD COOLING STUDIES - TOTAL COLIFORM, BACTERIA/100 grams (continued)

HOUR	BSKT NO.	TEST NUMBER 10	11	12	13	14	15	16	17
	1	400	410	490	2300	230	170	68	240000
		54000	120	230	220	160000	330	18	330
	3	460	220	230	93	170	330	68	110
		92000	170	130	210	18	260	170	210
0									
	2	3200	330	790	130	160000	410	210	700
		4900	140	330	45	330	1400	140	1300
	4	260	110	1100	490	170	450	61	140
		4900	330	310	8100	140	170	180	320
	1	3300	490	1100	270	20	3300	110	14000
		7000	1100	3300	170	18	810	390	2500
	3	17000	790	4900	2200	490	210	93	240000
		240000	170	1700	3300	1300	790	220	230
6									
	2	1100	140	490	490	36	220	4600	240000
		160000	170	230	1300	330	2300	170	160000
	4	260	260	220	35000	170	330	0	700
		340	1300	1100	330	40	450	45	490
	1	720	83	720	110	170	240000	170	560
		54000	1100	470	490	170	810	56	120
	3	24000	240	810	200	490	400	280	1400
		24000	640	120	480	950	240	420	170
25									
	2	490	1300	790	2200	460	810	240	240000
		1300	790	68	240000	1100	220	83	240
	4	790	290	790	1700	210	810	40	810
		17000	270	340	490	170	790	690	4300
	1	720	68	240000	2300	X	810	210	68
		35000	470	7000	790	4900	810	240	140
	3	35000	13000	2300	2300	X	8100	93	56
		160000	640	4900	2200	X	810	410	340
49									
	2	470	170	3300	270	1700	43000	0	320
		330	700	410	110	170	X	20	810
	4	340	480	330	260	X	450	200	130
		2200	700	2200	130	X	240000	380	240

DATA - 1975 ON-BOARD COOLING STUDIES
FECAL COLIFORM-BACTERIA/100 grams

HOUR	BSKT NO.	TEST NUMBER 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	1	0	0	0	45	40	20	0	0	20	110	0	0	0	0	0	0
		0	0	0	20	20	0	0	0	20	0	0	0	0	0	78	0
	3	0	20	0	78	20	0	0	20	0	0	0	0	0	0	0	20
		0	0	0	130	45	0	0	45	18	18	0	0	0	0	0	18
0																	
	2	0	36	20	170	0	0	0	110	0	0	20	0	0	0	0	40
		20	20	20	140	45	20	0	0	20	40	0	0	0	0	20	0
	4	0	20	40	45	0	20	20	20	0	20	0	20	0	20	0	0
		0	0	45	130	20	20	0	0	45	45	0	0	20	0	0	130
	1	68	0	110	45	0	20	20	40	20	68	20	20	0	0	40	18
		45	0	45	45	0	0	0	20	20	110	0	0	0	0	78	20
	3	18	20	40	170	20	68	0	78	45	78	0	0	78	45	0	0
		68	0	0	93	20	0	0	20	0	20	0	0	68	0	0	20
6																	
	2	0	40	45	110	0	68	0	20	0	220	0	0	0	0	0	68
		20	40	45	0	0	40	0	20	0	20	0	0	0	0	0	68
	4	0	0	20	78	0	40	0	0	0	45	0	20	0	45	0	0
		0	0	45	18	20	0	0	A	20	20	0	0	0	0	0	0
	1	0	0	20	45	0	0	20	20	0	61	0	110	0	20	20	0
		68	0	20	68	0	0	20	20	0	490	20	0	0	20	20	0
	3	0	20	40	78	18	0	0	20	20	0	0	20	0	20	0	20
		20	20	18	210	0	0	0	0	0	20	20	0	0	0	0	68
25																	
	2	0	78	68	20	40	20	0	20	18	0	20	0	0	0	0	110
		20	0	18	45	20	0	0	20	0	0	0	0	0	0	0	0
	4	20	0	20	110	0	20	0	20	18	78	18	0	18	20	0	0
		20	0	45	78	20	20	20	0	20	0	20	0	20	0	20	45
	1	45	0	110	130	110	120	20	0	140	170	0	0	0	68	68	0
		0	0	20	78	0	0	40	45	45	140	40	0	0	45	0	18
	3	40	0	0	78	0	0	0	0	20	110	20	0	20	X	20	40
		45	20	130	68	0	0	0	110	0	68	20	20	78	X	45	130
49																	
	2	20	0	20	170	45	0	20	45	68	20	78	20	0	0	X	0
		0	0	0	45	20	20	0	20	20	45	20	20	20	20	20	0
	4	0	0	45	110	0	0	0	20	20	45	0	45	20	X	0	45
		20	0	20	110	20	0	0	18	0	110	20	0	0	X	68	78

APPENDIX C

Outline Summary of Bacterial Analysis Procedures Used in this Study

PROCEDURE OUTLINE* FOR PROCESSING SOFT SHELL CLAMS FOR BACTERIAL ANALYSIS

1. Wash whole clam in tap water.
2. Shuck meats and siphons into a pre-weighed blender; ± 8 clams.
3. Weigh loaded blender; aim for 250 gms clam tissue including water.
4. For every 100 gms of clams add 100 ml buffer.
5. Homogenize for 60-90 seconds; this is now a 1:2 dilution.
6. Dilute homogenate:
   a. 20 ml of 1:2 homogenate into 80 ml buffer gives 1:10 dilution.
   b. 10 ml of 1:10 dilution above into 90 ml buffer gives 1:100 dilution.
   c. 10 ml of 1:100 above dilution into 90 ml buffer gives 1:1000 dilution.
7. Inoculate lactose media, 4 sets of 5 tubes per set:
   a. Put 2 ml of homogenate in each of the 5 tubes of the first set.
   b. Put 1 ml of 1:10 dilution in each of the 5 tubes of the second set.
   c. Put 1 ml of 1:100 dilution in each of the 5 tubes of the third set.
   d. Put 1 ml of 1:1000 dilution in each of the 5 tubes of the fourth set.
8. For plate count take .1 ml of 1:100 and 1:1000, add to 10 ml liquified agar in place, cover and incubate.
9. Suggested replacement for above step: Make additional 1:10,000 dilution, then plate 1.0 ml of 1:1000 and 1:10,000 on 10 ml liquified agar.
10. The lactose tubes are presumptive. Look for gas production at 48 hours. Any amount of gas is positive. No MPN data at this point. Incubation is at 37°C.
11. All positive lactose tubes are transferred by loop to two additional tubes, one containing Brilliant Green Bile solution, the other EC medium, keeping tract of the dilution of the original lactose set. The following are confirmed tests.
    a. BGB - each positive lactose tube generates one BGB tube. After 48 hours read number of positive tubes in each dilution set to get MPN of total coliform. Incubation is at 37°C.
    b. EC medium - each positive lactose tube generates one tube of EC medium. After 24 hours read number of positive tubes in each dilution set to get MPN of Fecal Coliform. Incubation is at 44.5°C.
12. Plates are incubated at 37°C, read at 48 hours. An estimate of the total number of colonies for each plate is established, but should be between 30 and 300.
    a. 0.1 ml of .01 dilution gives a dilution factor of 1000.
    b. 0.1 ml of .001 dilution gives a dilution factor of 10,000.
    c. For each plate, the plate count value is obtained by multiplying the colony count by the dilution factor.

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* The complete procedure for the bacterial analysis is available in the "Recommended Procedures for the Examination of Sea Water and Shellfish", 4th ed., 1970. American Public Health Association.

APPENDIX D

Abstract of Master of Science Thesis of
Robert Charles Morgan, whose work was
supported in part by this project.

ABSTRACT

Title of Thesis: Diagnostic Evaluation of Bacteria Associated with the Soft-Shell Clam, Mya arenaria, during Periods of Environmental Stress

Robert Charles Morgan, Master of Science, 1976

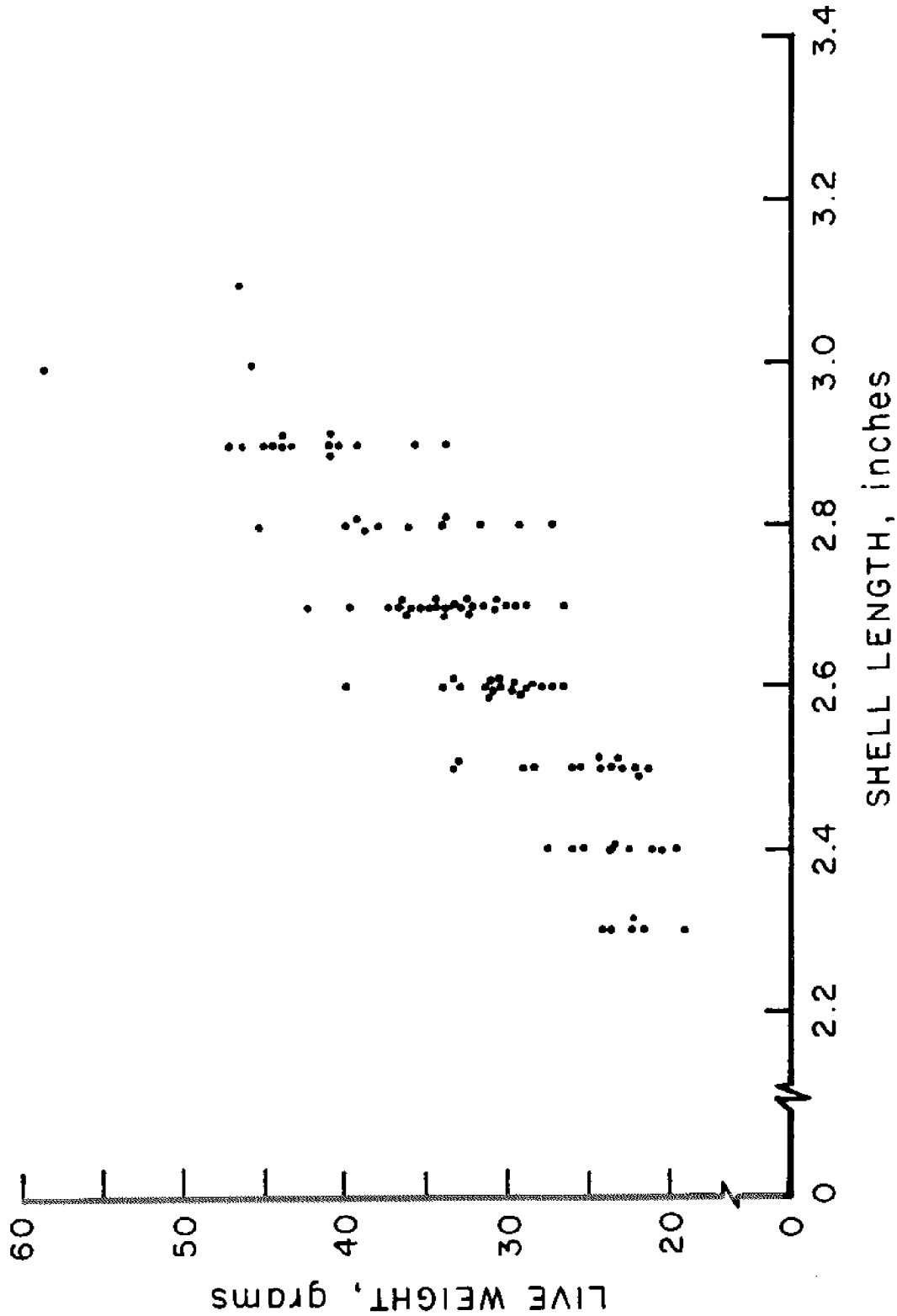
Thesis directed by: Assistant Professor Allen L. Ingling
Department of Veterinary Science
ADVP Graduate Program

A rapid diagnostic approach was devised to identify bacteria associated with the soft clam during high temperatures and low salinities. One hundred and twenty-five (125) aerobic bacterial cultures were collected from freshly harvested clams. Cultures were identified using generic classification schemes for aerobic bacteria of fish and shellfish and a commercial multitube micromethod. Predominant organisms found associated with the soft clam were: Aeromonas, Pseudomonas and members of the family Enterobacteriaceae. Less predominant organisms included Acinetobacter, Flavobacterium, Vibrio, Chromobacterium, Alcaligenes and Bacillus. Since species of the genera Vibrio and Aeromonas and a member of the family Enterobacteriaceae have been implicated in the literature for causing infection of the soft-shell clam during environmental stress, the diagnostic approach outlined in this study was considered adequate to identify aerobic bacteria associated with Mya arenaria including possible opportunistic pathogens.

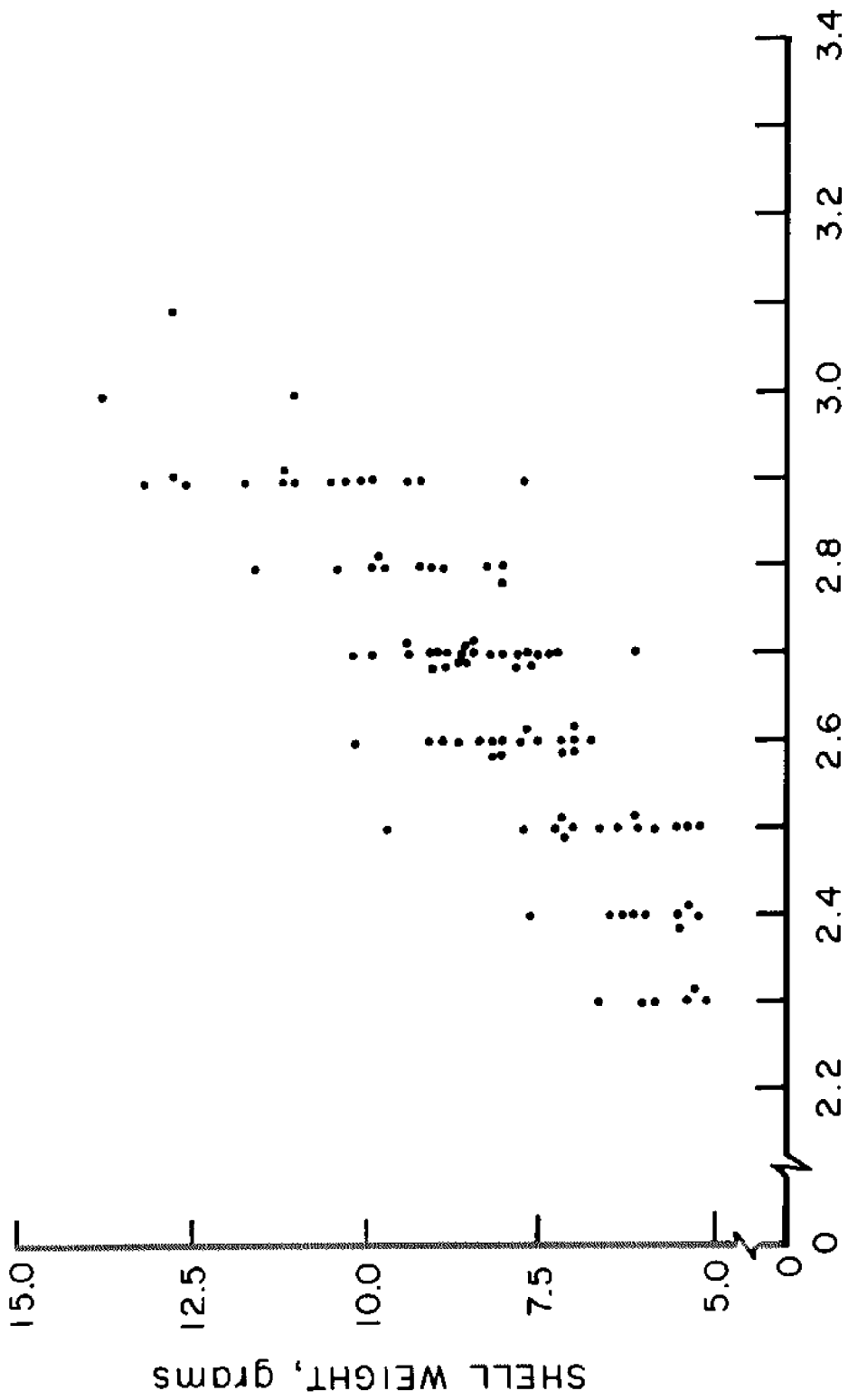
Stepwise multiple regression analysis was used to study the cumulative effect of sediment bacterial concentration, water bacterial concentration, water temperature and salinity with bacterial concentrations in the soft-shell clam. Sediment bacterial concentration, water bacterial concentration and water temperature significantly increased the multiple correlation and cumulatively accounted for a high degree of variation in bacterial concentration of the soft-shell clam. Simultaneously, the simple correlation coefficients for each independent variable were examined. Sediment bacterial concentration and water bacterial concentration were found significantly associated with clam bacterial concentration while temperature and salinity correlations were found non-significant.

APPENDIX E

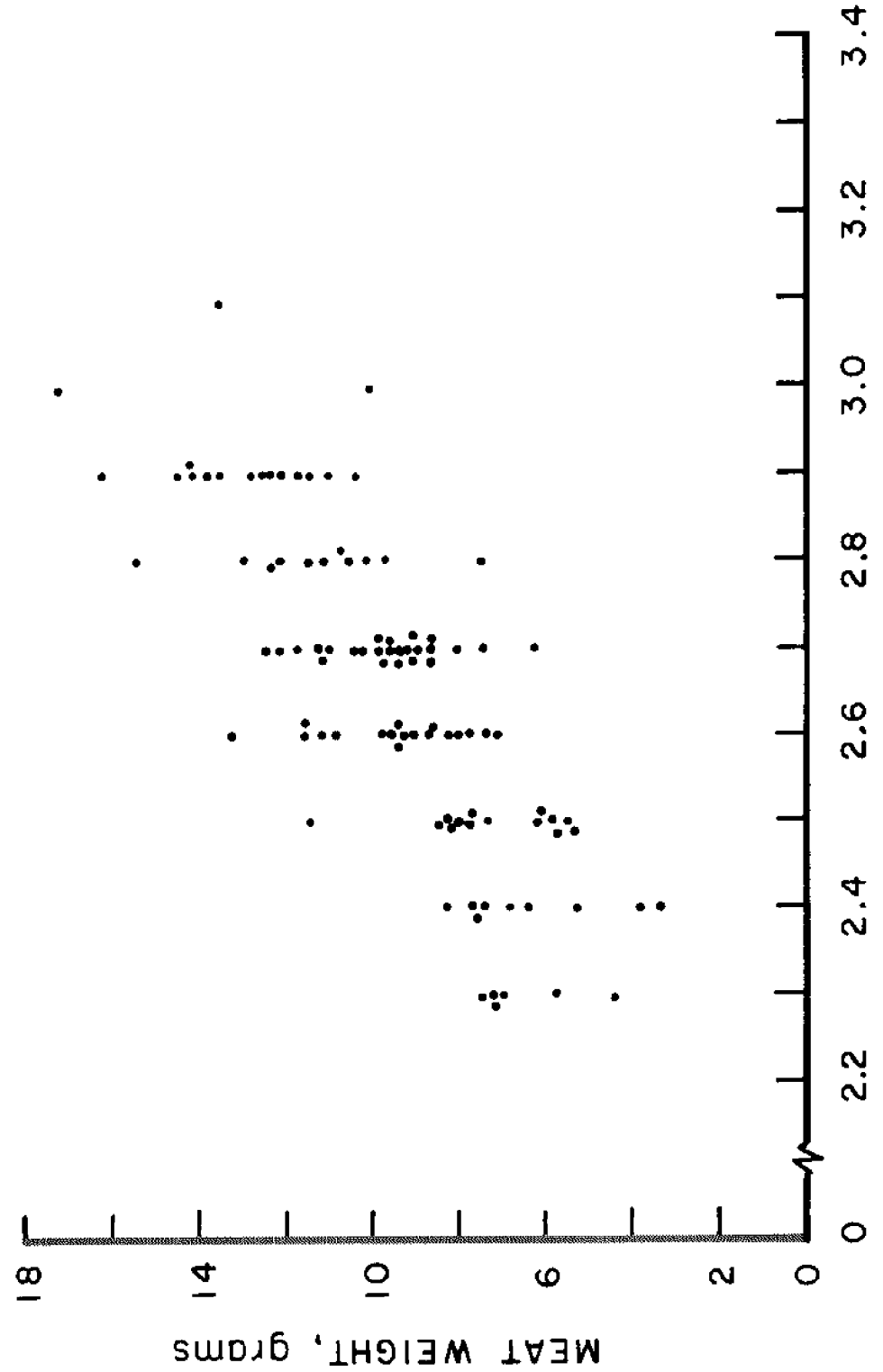
Example Plots of Clam Parts Data



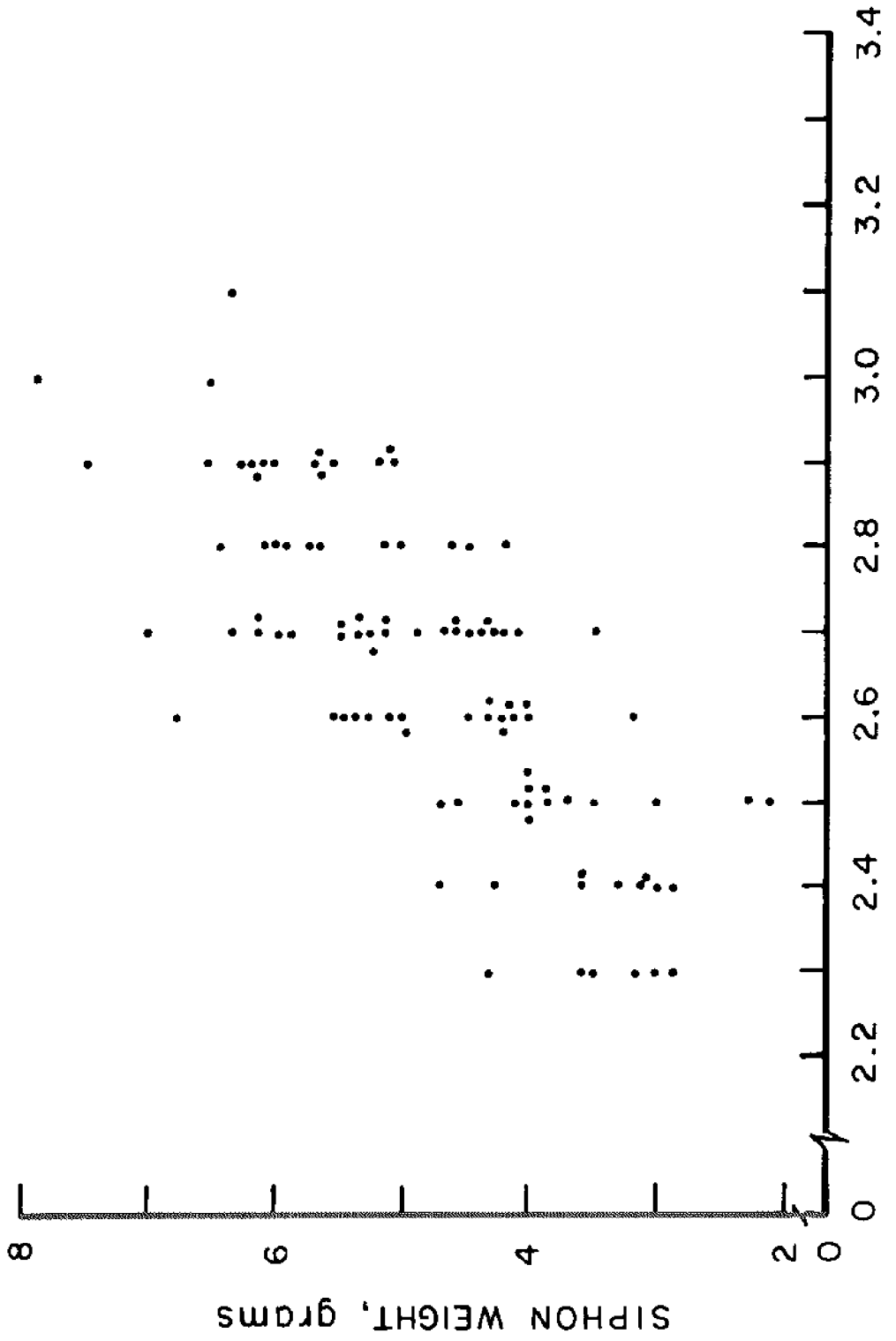
Relationship between live weight and shell length for marketable 6-1/2-shell clams harvested 3-13-75 from Shaw Bay.



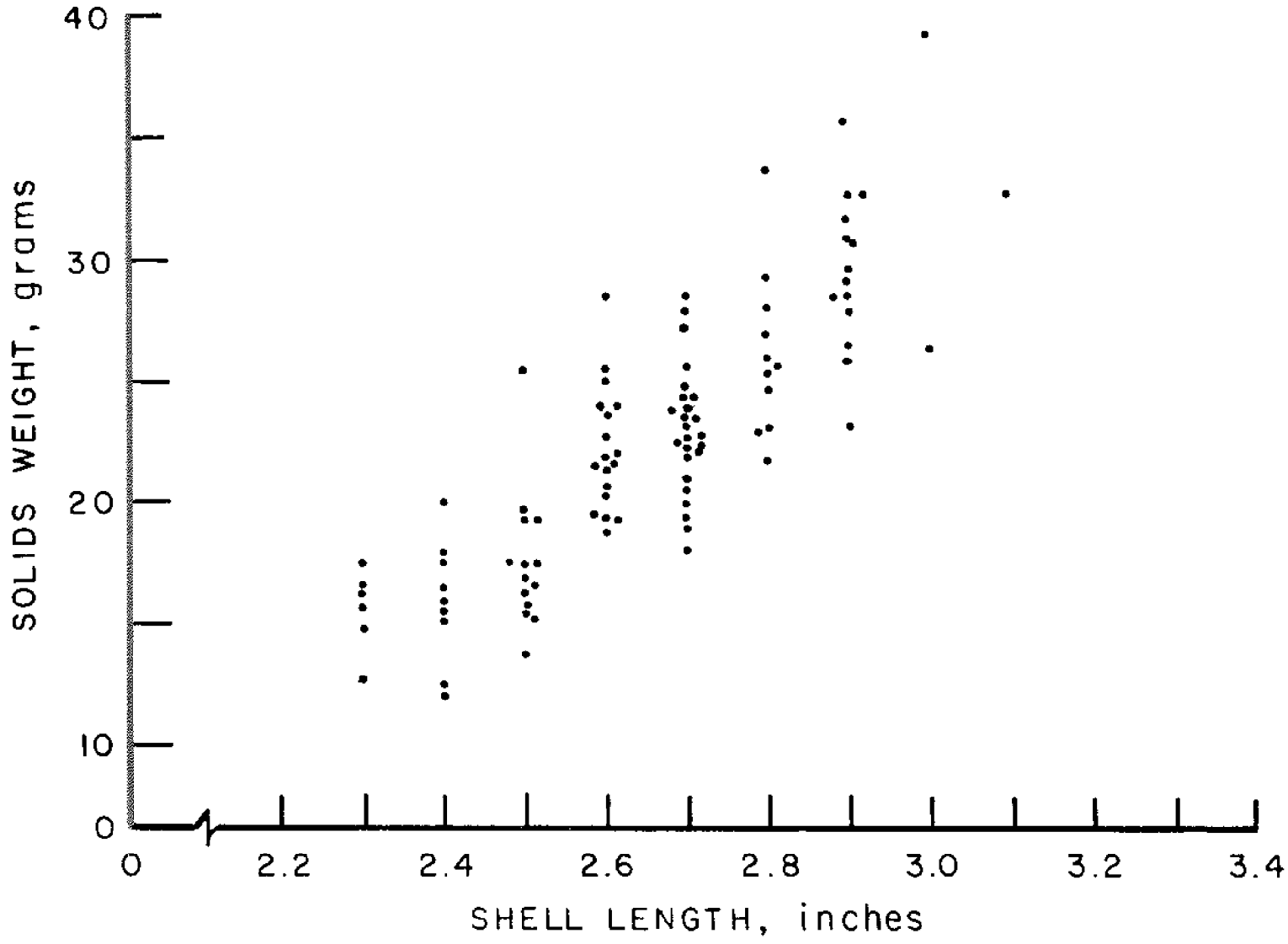
Relationship between shell weight and shell length for marketable soft-shell clams harvested 3-13-75 from Shaw Bay.



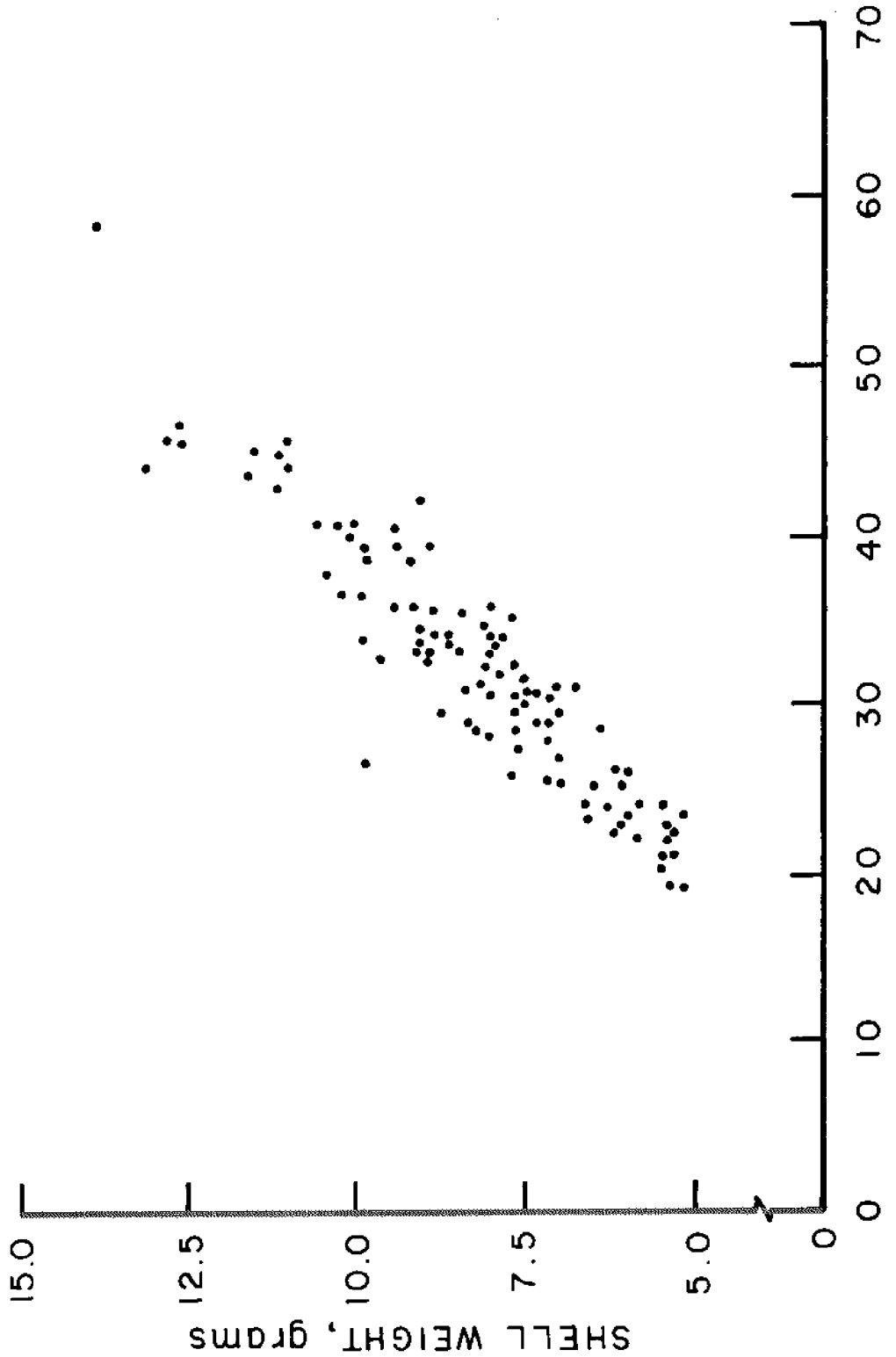
Relationship between meat weight and shell length for marketable soft-shell clams harvested 3-13-75 from Shaw Bay.



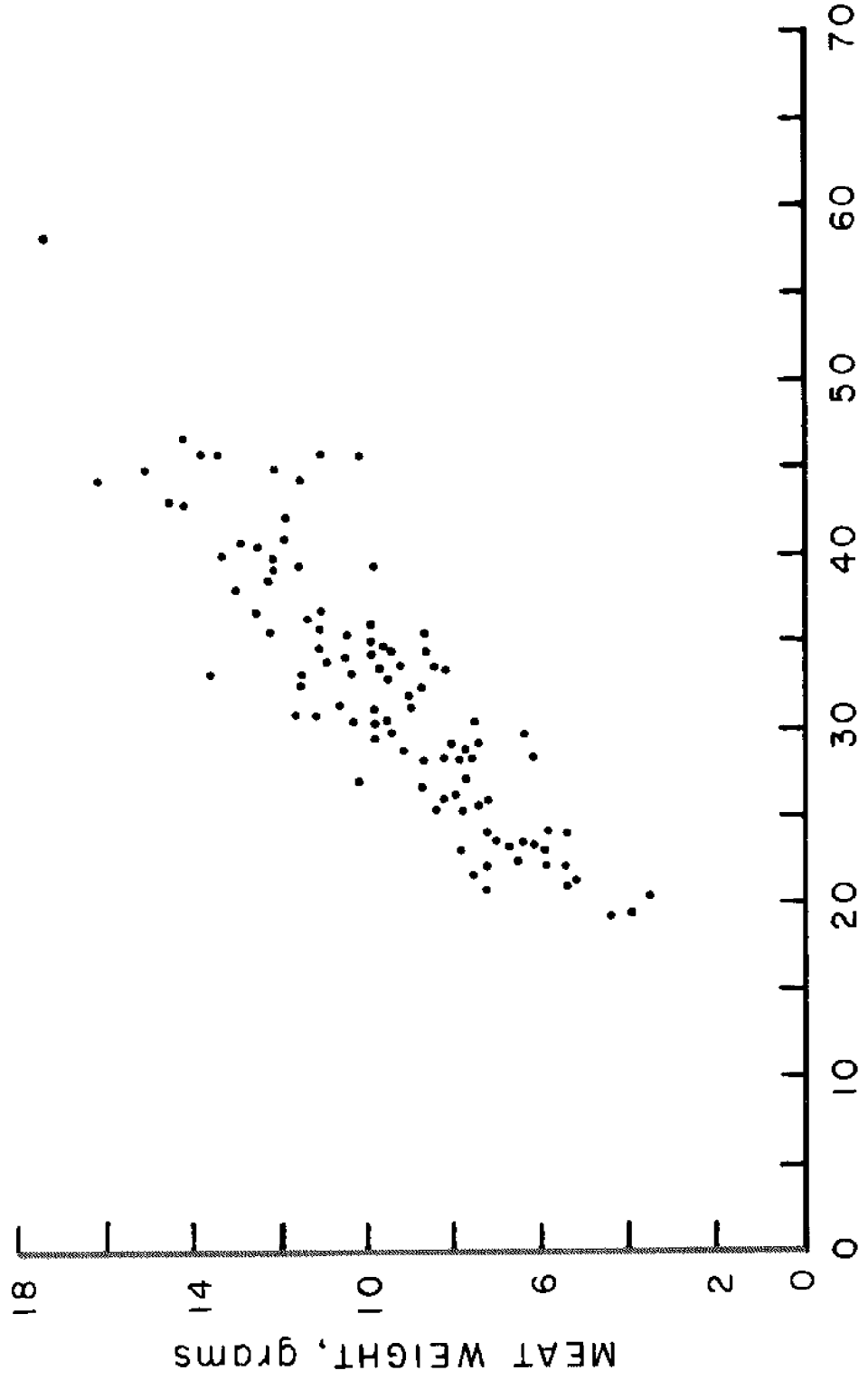
Relationship between siphon weight and shell length for marketable soft-shell clams harvested 3-13-75 from Shaw Bay.



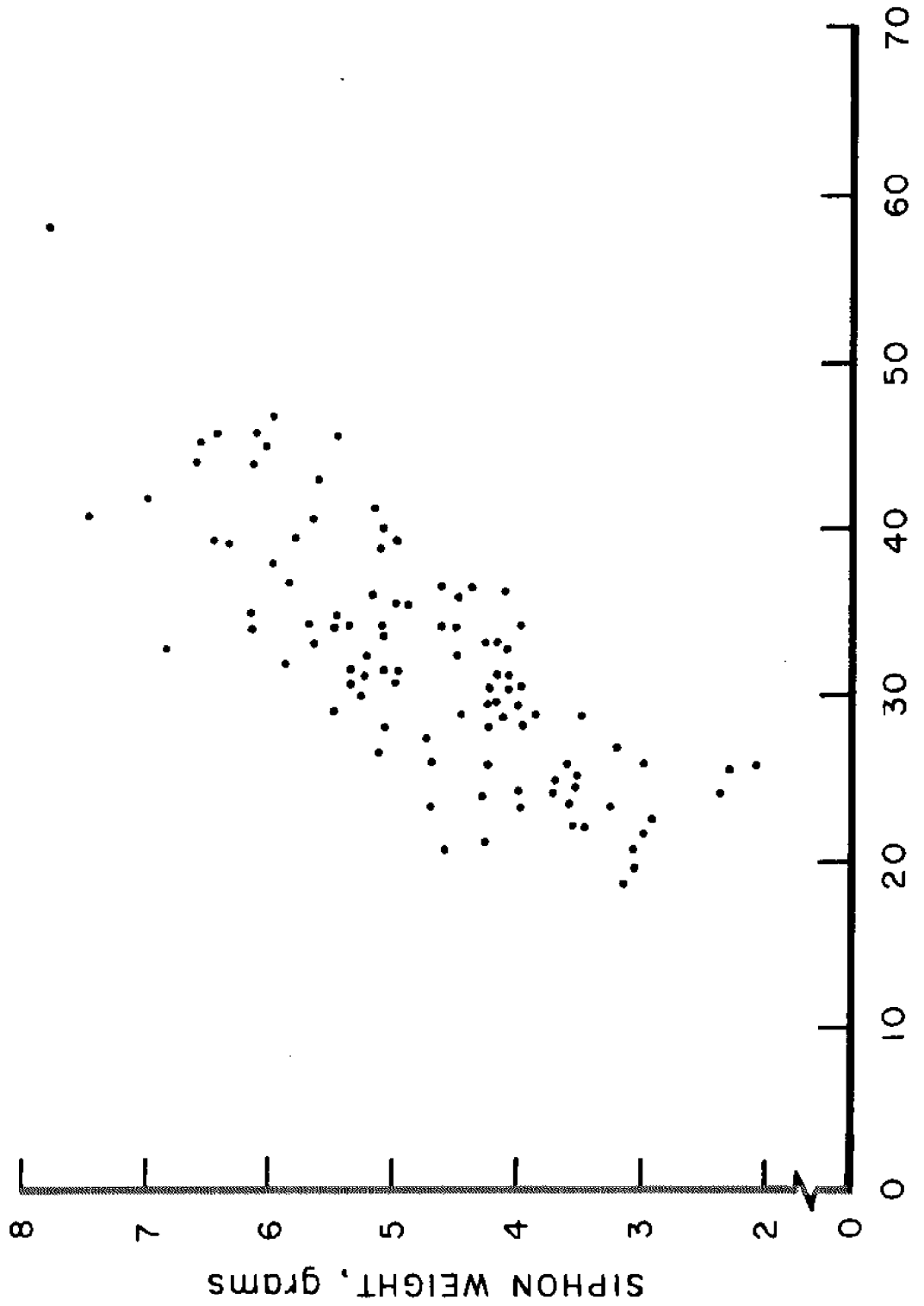
Relationship between solid weight and shell length [illegible] soft shell clams harvested 5-13-75 from Snow Bay.



Relationship of shell weight and live weight for marketable soft-shell clams harvested 3-13-75 from Shaw Bay.



Relationship between meat weight and live weight for marketable [illegible] shell
[illegible] harvested 3-13-77 from Shaw Bay.



Relationship between siphon weight and live weight for marketable soft-shell clams harvested 3-13-75 from Shaw Bay.